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**Evaluation of Automated
Decisionmaking Methodologies
and Development of an
Integrated Robotic System
Simulation**

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**EVALUATION OF AUTOMATED
DECISIONMAKING METHODOLOGIES
AND DEVELOPMENT OF AN
INTEGRATED ROBOTIC SYSTEM
SIMULATION**

**Appendix A—ROBSIM User's
Guide**

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INTRODUCTION

Overview

The purpose of the Robotic Simulation Program is to provide a broad range of computer capabilities to assist in the design, verification, simulation, and study of robotic systems. ROBSIM is programmed in Fortran 77 for use on a Digital Equipment Corporation VAX 11/750 computer under the VMS operating system.

These user's guides describe the capabilities of the ROBSIM programs, including the system definition function (creation or modification of simple or detailed arms, environments, loads or robotic systems), the analysis tools function (response or requirements simulation) and the postprocessor function (simulation or hardware motion playback or x-y plotting capability). The options a user may encounter with each of these executables are explained in detail and the different program prompts appearing to the user are included. Some useful suggestions concerning the appropriate answers to be given by the user are provided. An example user interactive run is enclosed for each of the main program services, and illustrations of some of the capabilities are shown.

This appendix is separated into four main sections. This section is an overview that presents the ROBSIM executive-level user/program interface procedure and describes several aspects of the program that are supervisory or common to the three separate executable parts of ROBSIM. The next three sections in this document describe the interactive programs: (1) system definition, (2) analysis tools, and (3) postprocessor.

The program command level. - A ROBSIM executive command procedure controls the runtime processes of the system definition function, analysis tools function or postprocessor function of the program. To run a ROBSIM function driver, the user should first execute the robotic simulation command file by typing:

@ROBSIM

The program will question the user for driver selection upon entering this top-level program. The user should then answer the prompt for program driver choice with "INITDRVR" (for system definition), "SIMDRVR" (for analysis tools), or "POSTDRVR" (for postprocessor). Upon receiving a valid function request, the ROBSIM command file transfers control to and executes the given processor. Specify:

INPUT (INITDRVR)-- TO RUN ROBSIM SYSTEM DEFINITION FUNCTION
 (SIMDRVR) -- TO RUN ROBSIM SIMULATION ANALYSIS TOOLS FUNCTION
 (POSTDRVR)-- TO RUN ROBSIM POST PROCESSOR FUNCTION

WHICH:

If the postprocessor was chosen, the user distinguishes which postprocessor executable by specifying whether the graphics terminal plotting executable or the x-y plotter executable should be run. The following prompt and program reply occur:

```
DO YOU WISH (1) TERMINAL OR (2) HARDCOPY PLOTTING?
ENTER INTEGER:
Previous logical name assignment replaced
Previous logical name assignment replaced
```

The ROBSIM command file level is reentered after FORTRAN STOP when the program run is complete and other processor instructions are queried. The user should acknowledge the following:

```
EXITING FROM [processor name] FUNCTION

FORTRAN STOP
```

At this point the command file will again prompt for execution directions. If it is desired to reexecute the current driver, the user should answer appropriately to:

```
INPUT (Y) TO RUN [processor name] FUNCTION AGAIN, (OTHERWISE, RETURN)

Choice of another driver is accomplished with depressing RETURN to:

INPUT (Q) IF YOU WISH TO EXIT THE PROGRAM (OTHERWISE, RETURN)
```

The process is repeated for each driver selection. An answer of Q (for quit) to the last executive level prompt terminates ROBSIM.

The ROBSIM help file access procedure. - During several input prompts, an integer input from the terminal of 911 signifies the user wishes to access the ROBSIM help file that prints user-input parameter definitions and/or some program I/O routine functional descriptions. The user is questioned for an appropriate subcategory relating to the type of information needed through a list of allowed qualifiers. The information opted will be printed to the terminal. After obtaining the requested help, enter successive RETURNS to exit the help utility and continue the ROBSIM program. For information pertaining to the creation and update of the program help file, see the ROBSIM programmer's guide. A sample entry into the help file option (Example A-1) follows.

Sample run: An example of the help file access follows:

Example A-1

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REPLAY GRAPHIC SIMULATION MOTION ONLY
2	REPLAY GRAPHIC SIMULATION VERSUS HARDWARE MOTION
3	PARAMETER VERSUS PARAMETER PLOTS
4	TERMINATE POST PROCESSOR EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

911

ENTER HELP KEYS (CARRIAGE RETURN FOR LISTING):

Information available:

INITDRVR POSTDRVR REQOPT SIMDRVR SIMOPT

Topic? POSTDRVR

POSTDRVR

THIS MODULE IS EXECUTED BY THE POST PROCESSOR

Additional information available:

PARAMETERS
FUNCTION

POSTDRVR Subtopic? FUNCTION

POSTDRVR

FUNCTION

The ROBSIM command file prompts the user for the program function desired. The three ROBSIM program functions are System Definition, Analysis Tools, and Post Processing. The user may also request program termination. Upon receiving a valid function request, the ROBSIM command file transfers control to and executes the appropriate function driver.

In the Post Processor executive, POSTDRVR, the result of executing option 1, is to call subroutine SIMOTION which provides a replay of the robotic system motion produced from a simulation run.

Option 2 provides a comparison of motion resultant from direct hardware theta values read and motion resultant from simulation execution, through subroutine HDWMOTIN.

If option 3 is selected, subroutine ROBPLT is called to provide parameter versus parameter plots of any of the data computed and written to a plot file during the Requirements or Simulation Analysis Tools Function.

Option 4 returns execution to ROBSIM command file level.

POSTDRVR Subtopic?

Topic?

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REPLAY GRAPHIC SIMULATION MOTION ONLY
2	REPLAY GRAPHIC SIMULATION VERSUS HARDWARE MOTION
3	PARAMETER VERSUS PARAMETER PLOTS
4	TERMINATE POST PROCESSOR EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

4

The ROBSIM constant parameter values - A file containing the maximum values of some parameters that affect the performance of the program execution is included in most subroutines:

(e.g., a maximum number of robotic arms per system,
a maximum number of joint/links per arm,
a maximum number of load objects,
a maximum number of point masses in each link or load,
a maximum number of graphics components per link,
a maximum number of graphics components in an environment,
a maximum number of data tablet points per component,
a maximum number of nonplanar entity points per component,
a maximum number of graphics components in each load object,
a maximum number of time segments in a motion history profile,
a maximum order for the polynomial describing a time history,
a maximum number of Y array data parameters in a plot file).

Changes to maximum allowable array sizes can be accomplished in most cases through modifications of the values set in this maximum parameter file. See the ROBSIM programmer's guide for more information and help in changing these parameter defaults.

File type conventions. - It is helpful to establish conventions for the various file name types used in the ROBSIM program. If a standard scheme is followed, it is less likely that the I/O files used during a run will be confused. Table A-I gives the typical appendages used during the creation, analysis and postprocessing phases.

TABLE A-I. - FILE NAME CONVENTIONS

APPENDAGE FOR FILENAME	DEFINITION
' .ARM'	Arm geometry file created during system definition
' .SYS'	System geometry file created during system definition
' .LOD'	Load geometry file created during system definition
' .ENV'	Environment geometry file created during system definition
' .OBS'	Obstacle file (nonplanar- X,Y,Z coordinates) read for detailed geometry input
' .ACT'	Actuator definition input file read by actuator module during system definition
' .GNS'	Response simulation gain input file
' .CON'	Response analysis control options input file read by control module
' .CNS'	Response simulation constraint input file
' .THT'	Hardware theta angle input file created from hardware conversion routine, and input during post processing
' .VLT'	Hardware voltage control signal input file created from hardware conversion routine, and input during response analysis execution
' .THP'	Time history profile file created by and input to requirements analysis
' .DAT'	Requirements or response simulation options input files; also some output files
' .PRT'	Simulation print output files
' .PLT'	Plot output files for X-Y pen plotter or graphics terminals
' .AGF'	Arm geometry print output files created during system definition

' .PIC'	Picture files for vector graphics displays, generated with HARD_COP routine; may be reproduced on the X-Y pen plotter after conversion to meta-file format
' .SOF'	Simulation output file for post processing
' .AVT'	Acceleration-velocity-theta output file
' .TRQ'	Torque output file
' .OUT'	Actual hardware output files for voltage control signals and corresponding theta angle values

The error message file. - This data file is addressed for rectification of user prompt input errors or other runtime problems. If an error has been encountered in a program aspect that is acknowledged in this error message file, an error indicator flag will be returned that equals the error message number to be written at the user terminal by a subroutine. The list of program error messages is saved in a file. The error flag is passed internally between subroutines, and determines the type message to be written to the user terminal. An example error message that the user might encounter is shown:

```

ERROR OCCURRED DURING SYSTEM DEFINITION FUNCTION
ERROR NUMBER = 120
INVALID RESPONSE TO LINK CENTER OF MASS INPUT MODE PROMPT
    VALID RESPONSES ARE INTEGER 1 OR 2
    INPUT MUST BE IN THE FIRST COLUMN
PROMPT WILL BE REISSUED

```

If a fatal error is met, the user will be prompted for the program termination request flag. The function disposition is given with the mode input:

```

FATAL ERROR OCCURRED DURING [processor function name]
ERROR NUMBER = [error number assignment]
[error message]

ENTER 1 TO REISSUE ROBSIM PROGRAM MODE PROMPT
ENTER RETURN TO TERMINATE PROGRAM

```

The ROBSIM graphics. - The Evans and Sutherland graphics, Fortran-callable routines are used for all graphics interaction opted during the system definition, analysis tools and postprocessor programs. Use of the accompanying simulation graphics capabilities in ROBSIM is optional; however, full utilization of the program capabilities is greatly limited without the graphics. This is especially true during system definition where visual depiction is a critical strength in accurate modeling of the robotic primitives for kinematic display and subsequent dynamics calculations. If the graphics function is desired, the graphics workstation must be assigned via individual facility procedures before running the ROBSIM command file.

System definition graphics: When environment, simple arm, detailed arm, load or system graphics is opted, the Evans and Sutherland display, extended switches/lights and analog control dials are initialized. A graphics display border is drawn; the type heading of the general display is chosen, either simple cylinder, detailed geometry, environment, load or system, and it is output for the system definition function driver currently under execution. During the run, the user is notified of the extended analog dials activation with the message:

```
*** E&S DIALS CONTROL OF GRAPHICS ***  
*** DISPLAY IS NOW ENGAGED          ***
```

```
DEPRESS FUNCTION SWITCH 31 TO DISENGAGE  
THE GRAPHICS LOOP AND CONTINUE
```

With these dials the user may change the translational, rotational and zoom perspectives of the displayed picture. Analog dial 1 allows a zoom perspective of the picture (changes the size of the display); dials 3 and 4 control the x-axis translation and rotation, respectively; dials 5 and 6 modify the y-axis translation and orientations of the picture; and dials 7 and 8 furnish the user the z-axis translation and rotation perspectives. When analysis in this manner is complete, depress key 31.

Analysis tools graphics: In the response simulation or requirements simulation phase of the analysis tools function one of the methods for controlling the motion of the manipulators' joints is via the external Evans and Sutherland extended switches. Only two robot arms, each with a maximum of six joints, may be programmed for this mode; key 5 controls arm 1 and key 6 will allow arm 2 movement. Key 4 specifies arm joint control, whereas key 10 implements an end-effector control scheme. If the end-effector type control is chosen, the user may opt for either a base (key 11) or tool (key 12) reference system for the relative arm motion. Translation is effected with key 13 and rotation of joints is accomplished through key 14. For joint control, key 16 and 22 are the joint 1 positive and negative angle motions, respectively; key 17 and 23 are the joint 2 positive and negative angle motions; keys 18 and 24 are for joint 3; keys 19 and 25 are for joint 4; keys 20 and 26 are for joint 5; and keys 21 and 27 are for joint 6. For end-effector control, 16 and 22 are the +x and -x buttons, respectively, for translation or rotation in the chosen reference system; keys 17 and 23 are for +y and -y translation or rotation; and keys 18 and 24 are for +z and -z. E&S key 9 will terminate the function key control session. The user will be allowed the use of an Evans and Sutherland extended function key reserved for cessation of simulation motion. While extended switch number 0 is activated, simulation motion is halted and the user is allowed the freedom to change the translational, rotational and zoom perspectives of the displayed picture through movement of the Evans and Sutherland extended analog dials. When analysis in this manner is complete, depressing the same function key number 0 resumes system motion and simulation time continues updating.

Postprocessor graphics: During simulation replay options of the post-processor function, the user is also allowed the use of an Evans and Sutherland extended function key reserved for cessation of system playback motion. While extended switch number 0 is activated, simulation playback is halted and the user is allowed the freedom to change the translational, rotational and zoom perspectives of the displayed picture through movement of the Evans and Sutherland extended analog dials. When analysis in this manner is complete, depressing the same function key number 0 resumes playback motion and simulation time continues updating.

Postprocessing plot capability access procedure. - The initial prompt at the user's terminal while executing the parameter versus parameter plot option in the postprocessor is installation-dependent. It informs the user of the required preliminary plot device allocation procedures necessary for this option. For the current version of ROBSIM, the message reads:

```
THIS PROGRAM USES THE DI3000 GRAPHICS SYSTEM
THE FOLLOWING SETUP PROCEDURES MUST HAVE BEEN
PERFORMED:
```

```
  RUN THE COMMAND FILE FOR DI3000 SETUP:
      @SYS DI:DI3000
```

```
  FOR HP 7221 PLOTTING RUN COMMAND FILE:
      HPSETUP
```

```
  FOR VT125 PLOTTING RUN COMMAND FILE:
      VTSETUP
```

```
  ENTER 1 TO TERMINATE PLOT SUBROUTINE IF THIS
  HAS NOT BEEN DONE
```

```
  ENTER RETURN TO CONTINUE
```

The setup exercises to be performed may vary with host computer, or they may be modified to fit the precedents established at the particular installation site.

The hardcopy utility access procedure. - If a hardcopy save file is wanted, that contains the resultant E&S display during the graphics option in the system definition, analysis tools or postprocessor, there is a capability for plotting it on the Hewlett-Packard x-y plotter and VT125 graphics terminal devices. The user may discover several messages during the ROBSIM program that appear as:

```
*** HARD COPY ***
```

```
ENTER ".PIC" FILE NAME PREFIX
(<CR> = NONE) :
```

An input for this included question allows regeneration of the Evans and Sutherland display as it appears at time of the utility call through use of an external program explained in the next subsection. The user input here should be the name of a picture file to create. If no hardcopy is desired, the user should depress RETURN when encountered with the prompt during running of ROBSIM with the graphics option selected.

Meta-file utility: If the user opts for a hardcopy, the picture file name entered from the terminal during the ROBSIM session will be appended with '.PIC' and saved in the user's directory. The program HCMFL should then be run to create a meta-file from the '.PIC' file. This executable will again ask the name of the file saved above (minus the suffix), and it will create filename '.MFL.' The specific typed text should be:

RUN HCMFL, and answer the file name question

To allocate the desired external hardcopy machine, input:

VTSETUP (for the VT125 graphics terminal)

or

HPSETUP (for the Hewlett-Packard)

In the same directory in which the meta-file is stored, after the corresponding device has been assigned, run the program by inputting:

VTMETTRNS (for the VT125)

or

HPMETTRNS (for the Hewlett-Packard)

Answer the prompts for the hardcopy plot properties; the E&S display will be transferred to the plot device. A general example, A-2, follows.

Sample run: An example run of the meta-file follows.

Example A-2

```
paper size          :1
pen speed           :3
# paper sheets :1
                    :<RETURN>
M>:S MF 1 metafile name .MFL
M>:D P 1
```

When the picture production is complete:

```
                    :<RETURN>
                    :<RETURN>
M>:EXIT
```

The hardware output data conversion utility. - The following explains the format used by the hardware interface program to create real data output files (both resolver-to-digital data and digital analog converter data) from an execution of a hardware planar arm. The hardware files are converted for later use in the postprocessing simulation vs hardware motion replay option. The contents of the hardware output file, per processing time step, are:

RECORD	INFORMATION
-----	-----
1	(data identification - text string)
2	(date and time data was acquired - text string)
3	(sample period at which data was acquired)
4	(reference signal - text string)
5	(control strategy - text string)
6	(number of data points)
7	(additional comments - text string)
8	(additional comments - text string)
9	(blank line)
10	(three data values)

A hardware conversion utility reads the data files. This routine must be modified to fit the particular user hardware system. The postprocessor section of this user's guide provides more information on the user-interactive hardware conversion utility execution.

Other Program Runtime Notes

Several program aspects deserve mention.

Abnormal exit from the program. - If during execution of the ROBSIM program, the user desires an abnormal termination of the program, an entry of <control Y> will stop the current process and return the user to the operating system command level. This may occur, perhaps, if the user enters a state in which a decision about the correct entry cannot be resolved or, possibly, if it is judged that the program is executing improperly.

Logical unit number assignments. - During each ROBSIM program, a routine set of logical units is used for all user input and output files. The default logical unit number assignments are set in one of the program routines. The message appearing at the terminal when executing any of the three main ROBSIM function drivers informs the user of the default LU number settings. The message is output as:

DEFAULT LOGICAL UNIT ASSIGNMENTS USED WITHIN ROBSIM

LU	USE
5	READ UNIT (TERMINAL)
6	WRITE UNIT (TERMINAL)
7	PRINTED OUTPUT UNIT
8-9	SIMULATION INPUT FILE
10	SIMULATION OUTPUT FILE
11	ACTUATOR PARAMETERS INPUT FILE
14	LOAD OBJECTS DATA FILE
15	ERROR MESSAGE FILE
16	GAIN CONSTANTS FILE
17	TORQUE DATA INPUT FILE
18	ACC-VEL-THETA FILE
19	PROGRAMS OPTIONS FILE

20	PLOT DATA FILE
21	MOTION TIME HISTORY FILE
22	HARDWARE CONTROL SIGNALS
23	CONTROL OPTIONS INPUT FILE
24	CONTROL MODULE OUTPUT FILE

USER WILL BE PROMPTED FOR FILENAMES
TO ASSOCIATE WITH EACH LOGICAL UNIT
WHEN REQUIRED

ENTER RETURN TO CONTINUE

The option typed to the user is for acceptance of or changes to these Fortran file assignments; request for modifications is not currently implemented. This array of logical unit numbers for read/write to the terminal, printed output and simulation input/output is kept in an internal common block.

User-specified input/output math units. - The user is asked to input the following flag during each ROBSIM system definition procedure:

WHICH UNITS DO YOU WISH TO USE FOR I/O?
ENTER 1 FOR METRIC UNITS
ENTER 2 FOR ENGLISH UNITS

Conversions are made to metric units used internally in all calculations. After answering, the I/O units to be used will then be printed for user acknowledgment. The format will depend on the units delegated, as shown.

Units for input/output are as follows:

	English units -----	metric units -----
Length	inches	meters
Velocity	inches/s	meters/s
Acceleration	inches/s**2	meters/s**2
Mass	pounds(mass)	kilograms
Inertia	lbm-in**2	kg-m**2
Force	pounds(force)	newtons
Torque	in-lbf	N-m

For all succeeding prompt inputs pertaining to the above entities, the entries should be reconciled in the appropriate I/O units.

THE SYSTEM DEFINITION USER'S GUIDE

This portion of the user's guide describes the use of the system definition function of ROBSIM that allows the construction of robotic workcell environments, manipulator arms, target load objects and total robotic systems. The user may save a variety of environment, arm and load object files in a directory, and may build different robotic system scenarios using these files. The robotic system ('.SYS') files are used as input to the analysis tools function of ROBSIM for requirements or response simulation analysis of the robotic arm and as input to the postprocessor function simulation motion replay options. A robotic system may include multiple robotic arms, an environment and a load objects file.

With this method, the system definition function provides the means for a so-called robotic library to be saved where permutations of the robotic workcell constituent files may be used alternately for various simulation runs. For instance, if a particular loads file is needed with a robotic arm during one task but a different loads file is needed for another task with the same arm then two separate robotic systems including the same robot arm, each employing the appropriate load objects file necessary for the task, may be built and saved on file for recall during the two different task simulations.

This ROBSIM function provides, as an option, Evans and Sutherland Multipicture System, MPS, graphics capabilities to aid the user in visualizing the robotic work cell members (environments, arms and loads) or the robotic system concurrently during construction.

The system definition function works in an interactive mode, prompting the user for the system definition option desired. Valid options are:

- 1) Create or modify an arm data file;
- 2) Create or modify a detailed environment file;
- 3) Create or modify load objects;
- 4) Create a robotic system data file;
- 5) Terminate system definition program execution.

After entry into the system definition, the question returned to the user from the program will be to choose one of the four subprocesses mentioned above or to end this program function. The user input should be an integer specifying a selection to the prompt:

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A-13

PRECEDING PAGE BLANK NOT FILMED

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SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE/MODIFY ARM DATA FILE
2	CREATE/MODIFY DETAILED ENVIRONMENT
3	CREATE/MODIFY LOAD OBJECTS FILE
4	CREATE SYSTEM DATA FILE
5	TERMINATE SYSTEM DEFINITION EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

In the system definition executive, the results of pursuing option 1 are further prompts as to the task to be performed on single-arm data. Option 2 will transfer the program jurisdiction to routines for inventing a detailed geometry environment file. For load objects, option 3 gives the user the ability to craft or modify a set of loads interactively. Lastly, the duty of combining an environment, a set of arm files (elaborate or simple) and load object file into a useful robotic system that describes the work cell is accomplished by the choice of option 4. The necessary simple cylinder or detailed single-arm file must exist before building a system.

At this point the discussion is separated into sections based on the menu options listed above. Mode 1 is discussed in the section entitled Procedure for Creating a Robot Arm; this section includes explanations of robotic arm initialization, simple cylinder or detailed geometric robot arm definition with graphics, and robotic arm modification. The user-specified mode 2 option is discussed in the section Procedure for Creating a System Workcell Environment; it explains definition of fixed environment properties and the detailed graphics prompts the user will encounter while including detailed environment components. The user option, mode 3, is covered under the heading Procedure for Creating a Load Objects File; it outlines the initial creation phase (with or without graphics) and modification mode questions for load objects files. Also, the construction of a total robotic system with option 4 is handled under the section, Procedure for Creating a Total Robotic System Workcell; it entails specification of the locations and orientations of the robotic arms, and optional environment and loads within the robotic workcell. A maximum number of robotic arms that may be included in any one system is predefined in the program.

Procedure for Creating a Robot Arm

This section documents the interactive conversation that is met when a selection to create or modify a robotic arm data file is chosen during the system definition function.

The user is asked to specify the graphics option in the ROBSIM arm creation phase of the system definition function with the following prompt:

**** ROBOT ARM DEFINITION ****

SPECIFY WHETHER GRAPHICS ARE DESIRED
DURING SYSTEM DEFINITION
** NOTE ** YOU MUST HAVE ASSIGNED AN
EVANS AND SUTHERLAND WORKSTATION
PRIOR TO RUNNING ROBSIM IN ORDER TO
REQUEST GRAPHICS

ENTER 1 FOR NO GRAPHICS
ENTER 2 FOR GRAPHICS

An answer of 2 should be input for the request flag if graphics are desired.

The course of action to be employed for the arm is selected with the flag:

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE ARM DATA FILE
2	MODIFY EXISTING ARM DATA FILE
3	SPECIFY DETAILED GEOMETRY
4	TERMINATE ARM DEFINITION

ENTER INTEGER VALUE FOR MODE DESIRED

The result of executing option 1, to create a new basic data file, is a file containing all data input during various routines within the system definition function, describing a simple cylinder robot arm. Option 2 provides for the modification of an existing arm data file previously created by the system definition function through interactive prompts similar to those issued originally. To specify a detailed geometric representation for a robotic arm file, option 3 should be used to replace a simple cylinder data file previously generated by option 1 or 2 or to create an additional arm file. A simple cylinder arm file created with option 1 or 2 must exist prior to selection of option 3. For all of these options, a robotic arm file will be written in a user-specified file name. Option 4, of course, returns control to the main system definition program level. These variations are described in the following paragraphs.

Procedure for creating an initial robot arm description. - The control of basic arm creation is through iterative calls to component initialization sub-routines that define the geometry and mass properties of the manipulator base, joints, links and tool system. Actuator parameters for dc motor drives can also be defined. In this mode, subroutines exist to generate only a simple cylinder model for each component and to display the system with line graphics. The user interface during these routines allows regeneration or correction of the arm structure currently in the program buffer (adding, deleting, transforming of links as desired during individual arm component entries or after construction of the total arm). All data generated during the arm description are stored in program COMMON blocks and subsequently stored in an arm data file.

The interactive inputs include:

SPECIFY SPAN, OR REACH, OF ARM IN [length units]

This input span value is used to scale any later graphics display of this arm file.

The following subsections [A) through G)] outline the objects that can be created under the various simple robotic arm definitions (base, joint, actuator, link, special joint, tool-joint, link-tool).

A) Arm base definition. - The manipulator base will be located in and oriented within the world coordinate system using the next several user inputs. These parameters should be in the I/O units previously opted by the user.

For definition of the base location:

SPECIFY X, Y, AND Z LOCATION OF BASE
IN WORLD COORDINATES. THE WORLD
COORDINATE SYSTEM IS DEFINED WITH
ORIGIN AT THE CENTER OF THE SCREEN

XW = POSITIVE TO THE RIGHT

YW = POSITIVE UPWARD

ZW = POSITIVE OUT OF THE SCREEN

ENTER BASE X LOCATION, IN [length units]

ENTER BASE Y LOCATION, IN [length units]

ENTER BASE Z LOCATION, IN [length units]

The user then inputs the rotations needed to specify the orientation of the base component in the world coordinate frame. The integer rotation axis indicator array allows rotation about the x, y or z axes for each rotation needed. With a maximum of three rotations, any orientation matrix necessary for the base may be defined. Each rotation has an associated angle the user must also type into the program. This angle must be specified in units of degrees. The prompts are, in order:

SPECIFY ROTATION SEQUENCE FOR ORIENTATION
OF BASE SYSTEM WITH RESPECT TO WORLD SYSTEM
SEQUENCE IS SPECIFIED BY A SERIES OF
ROTATION AXIS/ROTATION ANGLE PAIRS WHERE

1 REPRESENTS THE X AXIS

2 REPRESENTS THE Y AXIS

3 REPRESENTS THE Z AXIS

A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION

For the associated angle, input:

ENTER 1ST ROTATION ANGLE, IN DEGREES

Each successive rotation is multiplied by the current cumulative matrix. Continuation of these rotation axis/angle pairs is allowed until the user terminates the sequence of inputs via an entry of 2 at the question:

ENTER 1 TO SPECIFY ANOTHER ROTATION

ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT

The user then specifies the length of the "base-link" of the manipulator by inputting the values defining both the base-link ground and terminal (toward the direction of the first joint) x-axis end point coordinates with:

SPECIFY ENDPOINTS OF BASE IN BASE COORDINATE
SYSTEM. CENTERLINE OF BASE IS ALONG X AXIS

SO ONLY X VALUES ARE REQUIRED

ENTER X COORDINATE FOR BOTTOM OF BASE, IN [length units]
(SHOULD BE LESS THAN OR EQUAL TO ZERO)

and

ENTER X COORDINATE FOR TOP OF BASE, IN [length units]
(SHOULD BE GREATER THAN OR EQUAL TO DISTANCE
FROM BASE ORIGIN TO FIRST JOINT)

For the simple cylinder graphics representation, the following two inquiries pertaining to radius and number of sides for the base cylinder are met:

SPECIFY RADIUS AND NUMBER OF SIDES OF
BASE TO BE USED IN GRAPHIC REPRESENTATION

ENTER RADIUS OF BASE, IN [length units]

and

ENTER NUMBER OF SIDES FOR BASE
MUST BE AN INTEGER FROM 3 TO 9

Note that the parameters including radius (of base, link or tool), endpoints (the proximal and distal coordinates of base, link or tool), and number of sides (of base, link or tool) are needed only to compute the cylinder representation for the base, link or tool during the graphics, and for solving the standard equation of inertia of a right-circular cylinder. A more detailed representation of the base, link or tool physical appearance is possible through other routines within the system definition function, described further under the subsection Procedure for creating a detailed robotic arm geometry.

The user is given an opportunity to terminate the base definition or re-define any of the prior properties input for the base with the flag:

ENTER 1 TO BEGIN JOINT/LINK DATA INPUT
ENTER 2 TO REDEFINE BASE

If there are errors in this attempt at modeling the base, the user should type a 2 to change the base properties.

B) Arm joint definition. - In specifying the manipulator joints, the sequence for interactive description is given with the following.

The joint type indicator flag for each joint is input as:

SPECIFICATION OF DATA DEFINING JOINT I

SPECIFY JOINT TYPE

- 1 = HINGE JOINT (Y AXIS ROTATION)
- 2 = SWIVEL JOINT (X AXIS ROTATION)
- 3 = SLIDING JOINT (X AXIS TRANSLATION)

ENTER JOINT TYPE FOR JOINT I

[It must be noted that in the simulation, hinge joints rotate about the joint y-axis. Swivel joints rotate about the joint x-axis. Note that sliding joints are included in the definition phase and in the calculations that will later be performed during the analysis tools functions. Sliding joints move laterally along the joint x-axis. The x-axis of a joint coordinate system is directed along the centerline of the link between that joint and the next joint (or end-effector if the current joint is the final joint in the system). The orientation of the y-z plane is user-defined but is usually determined by the joint type (i.e., orientation of axis of rotation).]

The array holding x,y, and z location of the current joint in the previous joint coordinate system is loaded by the next question:

SPECIFY X, Y, AND Z LOCATION OF CURRENT JOINT

USING PREVIOUS JOINT COORDINATE SYSTEM

THE X AXIS IS DIRECTED FROM THE JOINT ALONG
THE CENTERLINE OF THE LINK BETWEEN THE PREVIOUS
JOINT AND THE CURRENT JOINT

THE YZ PLANE ORIENTATION IS USER DEFINED

NOTE THAT HINGE JOINTS ROTATE ABOUT THE Y AXIS

SWIVEL JOINTS ROTATE ABOUT THE X AXIS

AND SLIDING JOINTS MOVE ALONG THE X AXIS

ENTER X LOCATION OF JOINT I IN [length units]

ENTER Y LOCATION OF JOINT I IN [length units]

ENTER Z LOCATION OF JOINT I IN [length units]

The orientation of the current joint with respect to the previous joint coordination system is defined with user inputs to the following prompts.

SPECIFY ROTATION SEQUENCE FOR ORIENTATION OF CURRENT JOINT WITH RESPECT TO PREVIOUS JOINT.

SEQUENCE IS SPECIFIED BY A SERIES OF ROTATION AXIS/ROTATION ANGLE PAIRS WHERE

1 REPRESENTS THE X AXIS

2 REPRESENTS THE Y AXIS

3 REPRESENTS THE Z AXIS

A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION

ENTER 1ST ROTATION ANGLE, IN DEGREES

The series of coordinate axes rotations and specified angles are used to compute the relative transformations for the base, successive joints and tool geometric orientations. The rotation sequence continuation/termination flag is provided with:

ENTER 1 TO SPECIFY ANOTHER AXIS/ANGLE PAIR

ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT

For example consider Figure A-1:

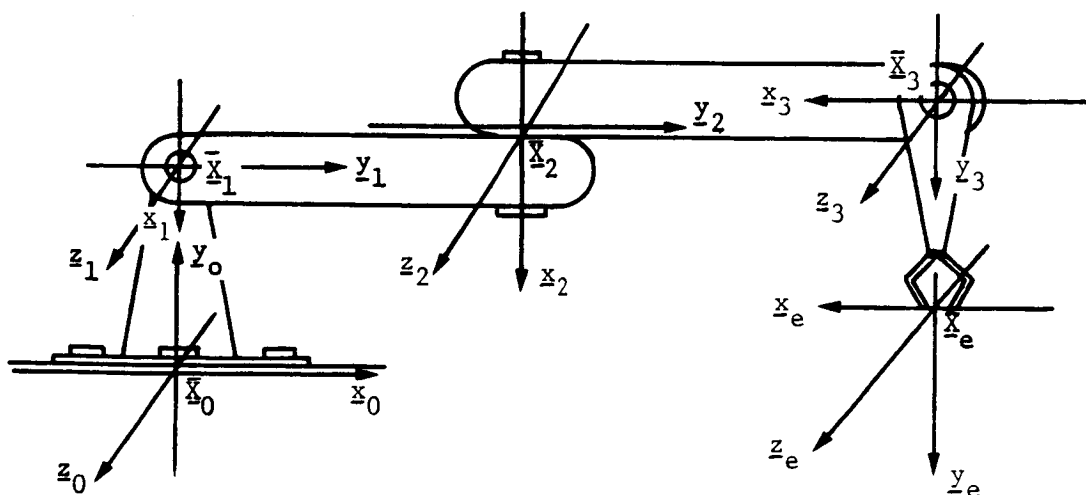


Figure A-1. - Manipulator coordinate systems.

To define joint 3 with respect to joint 2, the location should be given as n meters in the y_2 direction and 0 meters in the x_2 and z_2 directions. The orientation of joint 3 in the joint 2 coordinate system is -90° about the z_2 axis.

The initialization of the joint variable value, or home position, is next inquired. The input used should be reckoned in degrees for angular value joints (hinge or swivel), and in inches or meters for length value joints (sliding). The entry is given by:

SPECIFY INITIAL VALUE FOR CURRENT JOINT
VARIABLE. INITIAL ANGULAR ROTATION FOR
HINGE OR SWIVEL JOINTS, INITIAL LENGTH
FOR SLIDING JOINTS

ENTER INITIAL JOINT VARIABLE VALUE FOR JOINT I
IN DEGREES FOR ANGULAR VALUE
IN [length units] FOR LENGTH VALUE

The minimum and maximum distance travel limits for each joint are needed for the incorporated constraints during a simulation run. The user sets these physical limits for the joint movement with the two programmed values input during:

SPECIFY TRAVEL AND RATE LIMITS FOR CURRENT JOINT.
ENTER MINIMUM AND MAXIMUM ANGULAR ROTATION
POSSIBLE FOR HINGE OR SWIVEL JOINTS, MIN.,MAX.
LENGTH FOR SLIDING JOINTS

ENTER MIN.,MAX. TRAVEL LIMIT VALUES FOR JOINT I
IN DEGREES FOR ANGULAR VALUE
IN [length units] FOR LENGTH VALUE

Also, a maximum rate travel limit for each joint is assigned. For simplicity, the minimum will be set to the negative of the value input at:

ENTER MAXIMUM RATE FOR JOINT I
IN RADIANS/SEC FOR ANGULAR RATE
IN [velocity units] FOR SLIDING JOINT

C) Arm actuator definition. - In representing a motor actuator, the user will first be asked for a flag representing the choice of definition method:

DEFINITION OF ACTUATOR FOR JOINT I

DO YOU WISH TO DEFINE ACTUATOR PARAMETERS
FOR JOINT I

- 1 INPUT INTERACTIVELY THE ACTUATOR PARAMETER VALUES
- 2 READ A FILE FOR PARAMETER VALUE DEFINITION
- 3 NO ACTUATOR PARAMETER DEFINITION FOR JOINT I

Note that a selection of 3 infers there is to be no actuator included here. An example of an optional actuator ('.ACT') input file follows (Table A-II). It must be predefined and saved on file in the user's directory as presented. It should contain the characteristic values for each joint actuator of the arm and will be read, for each joint, into the program arrays during the arm creation phase. Note that the variable descriptions should be in columns 2-19 and their value assignments located in columns 20-60. The units displayed are of the metric I/O type selection, but may also be specified in English units. In the Table A-III, the respective shortened text array names are explained.

TABLE A-II. - THE ACTUATOR FILE FORMAT

TITLE	2-LINK PLANAR ARM CONTROL AND DYNAMICS TEST DATA
KI(1) (N*M/AMP)	3.584
RA(1) (OHMS)	2.8
N(1),A(1)(AMP/V)	20.25,10.
CFR(1),SFR(1)(N*M)	.439,.616
LA(1) (HENRIES)	1.E-04
KB(1) (V/RAD/SEC)	3.584
JT(1) (KG-M**2)	.0893
KT(1) (N*M/RAD/SC)	8.775E-02
KI(2) (N*M/AMP)	28.512
RA(2) (OHMS)	5.
N(2),A(2)(AMP/V)	86.4,15.
CFR(2),SFR(2)(N*M)	1.36,2.04
LA(2) (HENRIES)	.019
KB(2) (V/RAD/SEC)	28.512
JT(2) (KG-M**2)	.677
KT(2) (N*M/RAD/SC)	1.135
KI(3) (N*M/AMP)	55.288
RA(3) (OHMS)	8.75
N(3),A(3)(AMP/V)	4126.,17.5
CFR(3),SFR(3)(N*M)	1.34E-03,4.02E-03
LA(3) (HENRIES)	
KB(3) (V/RAD/SEC)	55.288
JT(3) (KG-M**2)	
KT(3) (N*M/RAD/SC)	1.396E+01

TABLE A-III. - EXPLANATION OF THE ACTUATOR FILE VARIABLES

TITLE	!TITLE OF ACTUATOR FILE; MAX. LENGTH- 40
KI(1) (N*M/AMP)	!*** LINK 1 *** MOT.TORQ.CONSTANT- K_{et} **
RA(1) (OHMS)	!MOTOR WINDING RESISTANCE- R_a
N(1),A(1)(AMP/V)	!GEAR RATIO- n ; AMP.GAIN- K_A
CFR(1),SFR(1)(N*M)	!COUL.FRIC.- K_{ec} ; ST.FRIC.- K_{es}
LA(1) (HENRIES)	!MOTOR WINDING INDUCTANCE- L
KB(1) (V/RAD/SEC)	!MOTOR BACK EMF- K_{emf}
JT(1) (KG-M**2)	!EFF.INERTIA- $I_{em} = I_m + I_{gr}$
KT(1) (N*M/RAD/SC)	!EFF.VIS.DAMP.MOT.&GR.(@MOT.SHFT.)- K_{ev}
KI(2) (N*M/AMP)	!*** LINK 2 *** MOT.TORQ.CONSTANT- K_{et} **
RA(2) (OHMS)	!MOTOR WINDING RESISTANCE- R_a
N(2),A(2)(AMP/V)	!GEAR RATIO- n ; AMP.GAIN- K_A
CFR(2),SFR(2)(N*M)	!COUL.FRIC.- K_{ec} ; ST.FRIC.- K_{es}
LA(2) (HENRIES)	!MOTOR WINDING INDUCTANCE- L
KB(2) (V/RAD/SEC)	!MOTOR BACK EMF- K_{emf}
JT(2) (KG-M**2)	!EFF.INERTIA- $I_{em} = I_m + I_{gr}$
KT(2) (N*M/RAD/SC)	!EFF.VIS.DAMP.MOT.&GR.(@MOT.SHFT.)- K_{ev}
KI(3) (N*M/AMP)	!*** LINK 3 *** MOT.TORQ.CONSTANT- K_{et} **
RA(3) (OHMS)	!MOTOR WINDING RESISTANCE- R_a
N(3),A(3)(AMP/V)	!GEAR RATIO- n ; AMP.GAIN- K_A
CFR(3),SFR(3)(N*M)	!COUL.FRIC.- K_{ec} ; ST.FRIC.- K_{es}
LA(3) (HENRIES)	!MOTOR WINDING INDUCTANCE- L
KB(3) (V/RAD/SEC)	!MOTOR BACK EMF- K_{emf}
JT(3) (KG-M**2)	!EFF.INERTIA- $I_{em} = I_m + I_{gr}$
KT(3) (N*M/RAD/SC)	!EFF.VIS.DAMP.MOT.&GR.(@MOT.SHFT.)- K_{ev}

If an actuator properties input file is to be read the input is:

ENTER FILENAME OF ACTUATOR PARAMETER FILE
TO BE READ. FILE MUST CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANAR.ACT

Otherwise, the user is prompted for each of the actuator properties. All of these questions occur in sequence and appear in a series as:

SPECIFY ACTUATOR TORQUE CONSTANT FOR JOINT I

SPECIFY MOTOR GEAR RATIO FOR
ACTUATOR OF JOINT I

SPECIFY ACTUATOR AMPLIFIER GAIN FOR JOINT I

SPECIFY ACTUATOR BACK EMF CONSTANT FOR JOINT I

SPECIFY MOTOR EFFECTIVE INERTIA FOR
ACTUATOR OF JOINT I

SPECIFY MOTOR WINDING RESISTANCE FOR
ACTUATOR OF JOINT I

SPECIFY MOTOR WINDING INDUCTANCE FOR
ACTUATOR OF JOINT I

SPECIFY COULOMB FRICTION COEFFICIENT FOR
ACTUATOR OF JOINT I

SPECIFY STATIC FRICTION COEFFICIENT FOR
ACTUATOR OF JOINT I

SPECIFY EFFECTIVE VISCOUS DAMPING COEFFICIENT FOR
ACTUATOR OF JOINT I

Note that the dry friction per joint is given with the static friction coefficient and the actuator viscous friction is determined by the effective viscous damping coefficient.

The actuator parameter data entered by the user are saved in the arm file and not in a separate actuator parameter file as yet.

D) Arm link definition. - For each arm link definition, the following conversation is encountered.

First the end points of the link between joints numbered (i) and (i+1), along the joint x-axis, are specified in the joint (i) coordinate system. The link-base endpoint and link-tool end point should be entered in the prespecified I/O units of length.

DEFINITION OF LINK FROM JOINT I TO JOINT I+1

SPECIFY END POINTS OF LINK BETWEEN JOINT I
AND JOINT I+1 IN JOINT I COORDINATE
SYSTEM. CENTERLINE OF LINK IS ALONG X AXIS
SO ONLY X VALUES ARE REQUIRED

ENTER X COORDINATE OF LINK BASE ENDPOINT,
IN [length units] (SHOULD BE LESS THAN OR EQUAL TO ZERO)

ENTER X COORDINATE OF LINK TOOL ENDPOINT, IN [length units]
(SHOULD BE GREATER THAN OR EQUAL TO THE DISTANCE
FROM JOINT I TO JOINT I+1)

The user is next encountered with prompts for link radius (in inches or meters) and for the number of sides to be used in the link representation:

SPECIFY RADIUS OF LINK BETWEEN JOINT I AND JOINT I+1
TO BE USED IN GRAPHIC REPRESENTATION

ENTER RADIUS, IN [length units]

and

SPECIFY NUMBER OF SIDES FOR LINK BETWEEN JOINT I AND JOINT I+1
TO BE USED IN GRAPHIC REPRESENTATION

ENTER INTEGER NUMBER OF SIDES FROM 3 TO 9

Next, the required mode for calculation of the link cg is warranted. Calculation is either internal to the program or user-specified:

SPECIFY CENTER OF MASS LOCATION BETWEEN JOINT I
AND JOINT I+1 IN JOINT I COORDINATE SYSTEM

ENTER 1 TO HAVE PROGRAM COMPUTE CENTER OF MASS
ENTER 2 TO REQUEST USER INPUT OF CENTER OF MASS

If the user wishes to interactively locate the link cg, input for the center of mass of the link between joints (i) and (i+1), in the joint (i) coordinate system follow with:

ENTER X COORDINATE OF CENTER OF MASS IN [length units]

ENTER Y COORDINATE OF CENTER OF MASS IN [length units]

ENTER Z COORDINATE OF CENTER OF MASS IN [length units]

Otherwise, the cg will be placed at the point that is half the length of the link in the link x direction.

The mass of the current link, in kilograms or pounds(mass), is designated with:

SPECIFY MASS OF LINK BETWEEN JOINT I AND JOINT I+1

ENTER MASS, IN [mass units]

The user is then asked to respond to inquiries for the method of definition of the link inertia, and the corresponding matrix input one column at a time, if opting an interactive definition mode. These are:

SPECIFY INERTIA MATRIX FOR LINK BETWEEN JOINT I AND JOINT I+1

ENTER 1 TO HAVE PROGRAM COMPUTE INERTIA MATRIX

ENTER 2 TO REQUEST USER INPUT OF INERTIA MATRIX

and, if the inertia matrix is to be typed as user-input:

ENTER 1ST COLUMN OF INERTIA MATRIX

INPUT 3 REAL NUMBERS SEPARATED BY COMMAS

INERTIA DATA SHOULD HAVE UNITS OF [inertia units]

ENTER 2ND COLUMN OF INERTIA MATRIX

INPUT 3 REAL NUMBERS SEPARATED BY COMMAS

INERTIA DATA SHOULD HAVE UNITS OF [inertia units]

ENTER 3RD COLUMN OF INERTIA MATRIX

INPUT 3 REAL NUMBERS SEPARATED BY COMMAS

INERTIA DATA SHOULD HAVE UNITS OF [inertia units]

Else, the inertia matrix calculated by the program is of the standard form for the inertia distribution of a right circular cylinder.

The flag specification to include point masses is then assigned. The modeling of a cylinder that is unbalanced in mass may be accurately accomplished with the point mass option. Any desired deviation from the inertia or cg of a standard cylinder, if not already specifically calculated and input in the previous question, may be effected with an answer of 1 to this option:

ENTER 1 TO SPECIFY POINT MASSES FOR LINK I

ENTER 2 NOT TO SPECIFY POINT MASSES FOR LINK I

If there are to be point masses defined along the link, the user is prompted for the following values until point mass definition is terminated. The interaction is given by:

SPECIFY MASS OF POINT MASS BETWEEN JOINT I AND JOINT I+1

IN [mass units]

and

ENTER X,Y,Z LOCATION OF POINT MASS J
IN JOINT I COORDINATE SYSTEM

ENTER 3 REAL NUMBERS IN [length units]

The location for each of these discrete mass values should be input for the link in the current joint coordinates. After the final point mass value and to continue the program, answer 2 for the question appearing as:

ENTER 1 TO CONTINUE POINT MASS INPUT
ENTER 2 TO TERMINATE POINT MASS INPUT

This point mass definition option is also available for the tool-link description. These unique point mass values will be combined with the component mass [e.g., (link or tool) mass + point masses] to obtain the total mass distribution for the joint/link and tool during robot arm creation. The mass, centroid locations and inertia matrix will be adjusted accordingly for the dynamics calculations. The results will be put in the COMMON locations for the robotic component.

The preceding joint, actuator and link prompts will be reissued for each iteration definition of existent arm constituents chosen by the user. A maximum number of iterations (i.e., maximum number of links) are allowed; this parameter value is set in a file, and it may be changed. At the end of each joint/link combination definition session, to terminate the current link and begin specifying the succeeding joint/link, enter a 2 here. When all links have been assigned properties, the choice selection to the next issued prompt should equal 3, to skip to the special joint, tool-joint and tool-link entries. To specify, answer:

ENTER 1 TO DEFINE ANOTHER JOINT/LINK COMBINATION
ENTER 2 TO REDEFINE CURRENT JOINT/LINK
ENTER 3 TO BEGIN TOOL DATA INPUT

Continuing in this manner, after a 3 is entered to the above question, the user is asked if any of the previously defined joints have special attributes [e.g., a special joint is one that does not fall into any one of the categories: hinge, swivel or sliding]. There will be special routines for handling the dynamics of these predescribed special joints as programmed for the specific joint properties. Enter the desired integer value for the flag:

DO YOU WISH ANY SPECIAL JOINTS?
ENTER 1 TO INCLUDE SPECIAL JOINTS
ENTER 2 FOR NO SPECIAL JOINTS

E) Arm special joint definition. - Among the special joint definition options, the user encounters a selection series including inputs for the number of special joints that are in this arm geometry, the special joint types and specifications of which joints are the special joints. It follows as:

HOW MANY SPECIAL JOINTS IN ARM?

For each special joint that exists:

ENTER JOINT TYPE FOR SPECIAL JOINT I
ENTER 1 FOR "GORDY JOINT"

WHICH JOINT IS SPECIAL JOINT I?

Note that "Gordy Joint" refers to a special two-degree-of-freedom joint. This is the only special joint currently modeled in ROBSIM.

F) Arm tool-joint definition. - In specifying the tool properties, the location for the tool needs to be given in terms of the final joint coordinate system. Input should be in the I/O units for length as a vector from the origin of this final joint reference system to the origin of the tool-joint reference system. The user answers:

SPECIFY TOOL LOCATION AND ORIENTATION WITH
RESPECT TO FINAL JOINT

SPECIFY X, Y, AND Z LOCATION OF TOOL
IN FINAL JOINT COORDINATE SYSTEM

ENTER X LOCATION OF TOOL, IN [length units]

ENTER Y LOCATION OF TOOL, IN [length units]

ENTER Z LOCATION OF TOOL, IN [length units]

Similar to the routines for orientation of the base and of each successive joint reference system, the rotation axis indicator array, the rotation angle in degrees and the rotation sequence continuation/termination flag are queried:

SPECIFY ROTATION SEQUENCE FOR ORIENTATION
OF TOOL SYSTEM WITH RESPECT TO FINAL
JOINT SYSTEM.

SEQUENCE IS SPECIFIED BY A SERIES OF
ROTATION AXIS/ROTATION ANGLE PAIRS WHERE

1 REPRESENTS THE X AXIS

2 REPRESENTS THE Y AXIS

3 REPRESENTS THE Z AXIS

A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION

and

ENTER 1ST ROTATION ANGLE, IN DEGREES

and

ENTER 1 TO SPECIFY ANOTHER AXIS/ANGLE PAIR
ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT

G) Arm tool-link definition. - Likewise, the prompts issued for the tool-link properties at initialization appear as those during joint/link creation. The end points of the tool (between the tool-joint and the tool end) are to be specified in the tool coordinate frame. The user is questioned:

DEFINITION OF TOOL

SPECIFY END POINTS OF TOOL
CENTERLINE OF LINK IS ALONG X AXIS
SO ONLY X VALUES ARE REQUIRED

ENTER X COORDINATE OF TOOL BASE ENDPOINT,
IN [length units] (SHOULD BE LESS THAN OR EQUAL TO ZERO)

ENTER X COORDINATE OF TOOL ENDPOINT, IN [length units]

The tool-link radius and number of sides for the generic cylinder representation are:

SPECIFY RADIUS OF TOOL
TO BE USED IN GRAPHIC REPRESENTATION

ENTER RADIUS, IN [length units]

and

SPECIFY NUMBER OF SIDES FOR TOOL
TO BE USED IN GRAPHIC REPRESENTATION

ENTER INTEGER NUMBER OF SIDES FROM 3 TO 9

Next, outline the tool mass properties computation methods and values:

SPECIFY CENTER OF MASS LOCATION OF TOOL
IN TOOL COORDINATE SYSTEM

ENTER 1 TO HAVE PROGRAM COMPUTE CENTER OF MASS
ENTER 2 TO REQUEST USER INPUT OF CENTER OF MASS

and if the user wishes to affect a particular cg, input this point locale between the tool-joint and tool end, as reckoned in the tool coordinate system:

ENTER X COORDINATE OF CENTER OF MASS IN [length units]

ENTER Y COORDINATE OF CENTER OF MASS IN [length units]

ENTER Z COORDINATE OF CENTER OF MASS IN [length units]

Also in the arm creation routine, define the basic tool mass value in kilograms or pounds(mass). The effect from the tool alone, excluding any planned load mass, is the value input here:

SPECIFY MASS OF TOOL

ENTER MASS, IN [mass units]

Set the tool inertia mass property value with:

SPECIFY INERTIA MATRIX FOR TOOL

ENTER 1 TO HAVE PROGRAM COMPUTE INERTIA MATRIX

ENTER 2 TO REQUEST USER INPUT OF INERTIA MATRIX

and, for the inertia explicit definition, for each matrix column, specify:

ENTER 1ST COLUMN OF INERTIA MATRIX

INPUT 3 REAL NUMBERS SEPARATED BY COMMAS

INERTIA DATA SHOULD HAVE UNITS OF [inertia units]

ENTER 2ND COLUMN OF INERTIA MATRIX

INPUT 3 REAL NUMBERS SEPARATED BY COMMAS

INERTIA DATA SHOULD HAVE UNITS OF [inertia units]

ENTER 3RD COLUMN OF INERTIA MATRIX

INPUT 3 REAL NUMBERS SEPARATED BY COMMAS

INERTIA DATA SHOULD HAVE UNITS OF [inertia units]

In determining the inclusion of point masses at the tool, input the flag:

ENTER 1 TO SPECIFY POINT MASSES FOR TOOL

ENTER 2 NOT TO SPECIFY POINT MASSES FOR TOOL

and for input of each point mass opted the following three responses are needed:

SPECIFY MASS OF POINT MASS IN TOOL

IN [mass units]

and

ENTER X,Y,Z LOCATION OF POINT MASS J
IN TOOL COORDINATE SYSTEM

ENTER 3 REAL NUMBERS IN [length units]

and

ENTER 1 TO CONTINUE POINT MASS INPUT

ENTER 2 TO TERMINATE POINT MASS INPUT

Termination of the tool definition is accomplished through answering:

ENTER 1 TO CONTINUE

ENTER 2 TO REDEFINE TOOL DATA

If the user wishes to regenerate any arm component property, this may be attempted when queried with the next printed prompt. The termination of arm generation is a dual function of this prompt by specification of a 1 as input. Enter:

ENTER 1 TO CONTINUE
ENTER 2 TO MODIFY ARM DATA

When a completely satisfactory simple arm has been built, the answer of 1 will return the user to the system definition function main routine.

Procedure for modifying an initial robot arm description. - The following process is outlined for modifying a simple cylinder robot arm on file. This is accomplished through an appropriate answer to the aforementioned prompts for modification of the current component during the initial creation phase, or an answer of 2 to the system definition mode:

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE ARM DATA FILE
2	MODIFY EXISTING ARM DATA FILE
3	SPECIFY DETAILED GEOMETRY
4	TERMINATE ARM DEFINITION

ENTER INTEGER VALUE FOR MODE DESIRED

Also an answer of 2 for the manipulator arm termination flag in the subsection above, Procedure for creating an initial robot arm description, will result in the program interaction described here.

The user interface during these routines allows regeneration or correction of the arm structures previously saved for a particular arm file. It is possible to add, delete or transform the base, joints, actuators, links or tool as desired with appropriate answers to each individual arm component modification entry.

This option may be selected for modification of an existing data file containing detailed geometric data. However, modifications should be limited to data not pertaining to the system geometry or configuration of joints and links (i.e., the arm configuration is defined by joint locations and relative orientations). Modifications in these areas will destroy the detailed data and replace it with simple cylinder data.

A subroutine may read the unformatted data file created by the system definition function containing the contents of pertinent COMMON blocks defining the robotic arm to be modified. The user is prompted for the file name under which the file is stored, and for a disposition of save or delete. It is customary for these saved arm files to have a suffix of '.ARM'. The terminal inputs are:

ENTER FILENAME OF ARM DATA FILE
TO BE MODIFIED
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANIN.ARM

ARM DATA FILE HAS BEEN READ
ALL COMMON BLOCKS ARE LOADED

and

SPECIFY DESIRED DISPOSITION OF
ARM DATA FILE
ENTER 1 TO SAVE FILE FOR FUTURE USE
ENTER 2 TO DELETE FILE

If the user is sure to be overwriting the file with the modified version, then an answer of 2 is in order; if a disposition of delete is encountered, a program reevaluation of the user's intention is forthcoming:

*** DELETION OF FILE REQUESTED ***
ENTER 1 TO VOID DELETION REQUEST
ENTER RETURN TO VERIFY DELETION REQUEST

After input of the name of the arm file that is to be changed, the values input previously during the arm creation session defining the arm base, joints, actuators and links are available in the user's program buffer.

To modify a particular value, skip through to the component in need of changes with successive input integer category choices specifying termination of the current component modification mode. Enter an appropriate response signifying the start of a new link (or tool) as they are met for each joint/link combination in the arm geometry until the component for modification is encountered. This option may also be used for parsing through each of the components (base, links and tool) solely for the purpose of a review of the arm display or output of an Arm Geometry printout file.

An opportunity to initialize a graphics display representing the arm is again issued. Also, a chance to change the arm span specification is given by the prompt:

ENTER 1 TO KEEP EXISTING SPAN
ENTER 2 TO MODIFY SPAN

Base modifications: If overwriting a base descriptor, interactive prompts exactly like those outlined above under subsection A) will appear to the user. The new robotic system base position and orientation within the world coordinate system or base physical dimensions (end points, radius or number of sides) will be cross-examined:

MODIFICATION OF SYSTEM BASE DATA
SELECT CATEGORY OF DATA TO BE MODIFIED

CAT	DEFINITION
1	BASE LOCATION
2	ROTATION SEQUENCE AND ROTATION ANGLES
3	BASE END POINTS
4	BASE RADIUS AND NUMBER OF SIDES
5	TERMINATE BASE MODIFICATIONS

ENTER INTEGER MODIFICATION CATEGORY DESIRED

Joint modifications: In the modification mode for joint parameters the user is allowed to redefine joint type, joint location as Cartesian coordinates in terms of the coordinate system of the previous joint (or base if the current joint is joint 1), joint orientation as a rotation sequence of axes and corresponding angles with respect to the previous joint coordinate system (or base if joint 1), initial joint state (initial angle for hinge or swivel or initial length for sliding joints), and joint travel limits.

For modifications to the joints, the process is like that laid out in subsection B. The link modification category selection occurs after entering a value of 1 for the flag:

ENTER 1 TO BEGIN JOINT/LINK DATA INPUT
ENTER 2 TO REDEFINE BASE

Selection of the necessary modification category is effected with:

MODIFICATIONS TO JOINT I DATA
SELECT CATEGORY OF DATA TO BE MODIFIED

CAT	DEFINITION
1	JOINT TYPE
2	JOINT LOCATION
3	ROTATION SEQUENCE AND ROTATION ANGLES
4	INITIAL JOINT VARIABLE VALUE
5	JOINT MIN.,MAX. TRAVEL LIMIT VALUES
6	TERMINATE JOINT I MODIFICATIONS

ENTER INTEGER MODIFICATION CATEGORY DESIRED

Actuator modifications: For adding an actuator to an existing file or modifying any predefined actuator properties, the user may again choose the mode for definition. The actuator represents the motor at the current joint under construction. The user may wish to interactively prompt for actuator parameter values or may desire to read a previously constructed file of actuator parameter values.

During modifications, the actuator routine will require the input of the modification category with the resulting prompts as explained in the prior enumeration C. The user may opt to change the mode of definition to/from interactive construction or the file-specific variety. The user chooses:

ACTUATOR DATA MODIFICATIONS
SELECT CATEGORY OF DATA TO BE MODIFIED

CAT	DEFINITION
1	ACTUATOR EXISTANCE AND DEFINITION METHOD
2	MOTOR TORQUE CONSTANT
3	GEAR RATIO
4	AMPLIFIER GAIN
5	MOTOR BACK EMF CONSTANT
6	MOTOR EFFECTIVE INERTIA
7	MOTOR WINDING RESISTANCE
8	MOTOR WINDING INDUCTANCE
9	COULOMB FRICTION COEFFICIENT
10	STATIC FRICTION COEFFICIENT
11	MOTOR EFFECTIVE VISCOUS DAMPING
12	TERMINATE ACTUATOR MODIFICATION

ENTER INTEGER MODIFICATION CATEGORY DESIRED

Link Modifications: During modifications for links, the user may change the link end points (in coordinates along the x-axis), link radius in I/O units of length (previously specified as meters or inches), the location of center of mass as the Cartesian coordinates of the center of gravity in the coordinate system of the joint at the "base" end of the link, link mass, inertia matrix relative to the joint at the "base" end of the link and the number of sides for the desired simple cylinder to be used by the graphics routines for redisplay. The coordinate system of the joint at the "base" end of the link should also be used as the reference for the link point mass locations input.

During the modification mode of the link definition session, to motivate the previously printed link properties input cues, the user selects:

LINK DATA MODIFICATIONS
SELECT CATEGORY OF DATA TO BE MODIFIED

CAT	DEFINITION
1	LINK END POINTS
2	LINK RADIUS
3	LINK NUMBER OF SIDES
4	LINK CENTER OF MASS
5	LINK MASS
6	LINK INERTIA MATRIX
7	POINT MASS VALUES AND LOCATIONS
8	TERMINATE LINK MODIFICATION

ENTER INTEGER MODIFICATION CATEGORY DESIRED

Tool-joint modifications: The tool-joint setup may be altered with a new user-specified location for the tool as Cartesian coordinates of the origin of the tool coordinate system, given in terms of the coordinate system of the final joint in the robotic system. The orientation of the tool (end-effector) as a rotation sequence and corresponding set of rotation angles that define orientation of the tool coordinate system with respect to the coordinate system of the final joint are also modified via the options following an input of 3 to the prompt:

ENTER 1 TO DEFINE ANOTHER JOINT/LINK COMBINATION
ENTER 2 TO REDEFINE CURRENT JOINT/LINK
ENTER 3 TO BEGIN TOOL DATA INPUT

For changes to the definition for the tool-joint location or orientation the user may contemplate the list:

MODIFICATIONS TO TOOL DATA
SELECT CATEGORY OF DATA TO BE MODIFIED

CAT	DEFINITION
1	TOOL LOCATION
2	ROTATION SEQUENCE AND ROTATION ANGLES
3	TERMINATE TOOL MODIFICATIONS

ENTER INTEGER MODIFICATION CATEGORY DESIRED

Tool-link modifications: In modify mode for the tool-link the user is interactively prompted for tool end points in coordinates along the x-axis, tool radius in I/O length units, location of the center of mass of the end-effector as Cartesian coordinates of the center of gravity in the coordinate system of the joint at the "base" end of the tool, tool mass, inertia matrix relative to the joint at the "base" end of the tool, the number of sides for the desired simple cylinder to be used by the graphics, and the tool point mass values and relative locations.

If the modify mode is enacted, the choices of the tool-link properties that may be modified will appear:

TOOL DATA MODIFICATIONS
SELECT CATEGORY OF DATA TO BE MODIFIED

CAT	DEFINITION
1	TOOL END POINTS
2	TOOL RADIUS
3	TOOL NUMBER OF SIDES
4	TOOL CENTER OF MASS
5	TOOL MASS
6	TOOL INERTIA MATRIX
7	POINT MASS VALUES AND LOCATIONS
8	TERMINATE TOOL MODIFICATION

ENTER INTEGER MODIFICATION CATEGORY DESIRED

Graphics during simple cylinder arm creation or modification. - If the graphics function is initiated during the simple single arm creation or modification, subroutines are provided with graphics capability for the simple cylinder representation of the robotic manipulator. The display includes the base, joint/link combinations and the tool as defined. During the modification mode, the graphics is handled appropriately; component deletions, additions and changes are visually reported.

As the user begins a component definition, the current coordinate axis frame for the component (base, joint/link or tool) will be shown. The x,y,z axes are color-coded for the user's convenience. The x,y,z axes will appear as red, white and blue, respectively.

During any graphics involvement, the user will be allowed to utilize the Evans and Sutherland extended analog control dials for changes of translational, rotational and zoom perspective to the displayed picture. In this manner, mistakes in the model may be detected at an early stage, corrected and generation of the arm continued. When the user is ready to end the control dials loop and continue to the next link, Evans and Sutherland extended function key number 31 should be depressed to deactivate the dials loop.

The simple arm data created are stored in program COMMON blocks, and represent right circular cylinders of the specified sizes for each system component (the base, each link and the tool) that may be used by the graphics package to draw the arm during the system definition function. The simple cylinder representation was chosen for ease of data point computation, ease of modification, and acceptability of use as a coarse representation of most robotic system components. The use of simple cylinder representations allows the addition and deletion of links for quick study of various system configurations.

Sample run. - The inserted pages (Example A-3) show a typical run of a simple arm creation. Figures A-2 through A-6 show the graphics displays created during this simple arm generation.

Example A-3

@ROBSIM
INPUT (INITDRVR)-- TO RUN ROBSIM SYSTEM DEFINITION FUNCTION
 (SIMDRVR) -- TO RUN ROBSIM SIMULATION ANALYSIS TOOLS FUNCTION
 (POSTDRVR)-- TO RUN ROBSIM POST PROCESSOR FUNCTION
WHICH:INITDRVR
Previous logical name assignment replaced
Previous logical name assignment replaced

ROBOTIC SYSTEM SIMULATION PROGRAM (ROBSIM)

ENTERING SYSTEM DEFINITION FUNCTION

DEFAULT LOGICAL UNIT ASSIGNMENTS USED WITHIN ROBSIM

LU	USE
5	READ UNIT (TERMINAL)
6	WRITE UNIT (TERMINAL)
7	PRINTED OUTPUT UNIT
8-9	SIMULATION INPUT FILE
10	SIMULATION OUTPUT FILE
11	ACTUATOR PARAMETERS INPUT FILE
14	LOAD OBJECTS DATA FILE
15	ERROR MESSAGE FILE
16	GAIN CONSTANTS FILE
17	TORQUE DATA INPUT FILE
18	ACC-VEL-THETA FILE
19	PROGRAMS OPTIONS FILE
20	PLOT DATA FILE
21	MOTION TIME HISTORY FILE
22	HARDWARE CONTROL SIGNALS
23	CONTROL OPTIONS INPUT FILE
24	CONTROL MODULE OUTPUT FILE

USER WILL BE PROMPTED FOR FILENAMES
TO ASSOCIATE WITH EACH LOGICAL UNIT
WHEN REQUIRED

ENTER RETURN TO CONTINUE

<CR>

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE/MODIFY ARM DATA FILE
2	CREATE/MODIFY DETAILED ENVIRONMENT
3	CREATE/MODIFY LOAD OBJECTS FILE
4	CREATE SYSTEM DATA FILE
5	TERMINATE SYSTEM DEFINITION EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

1

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE ARM DATA FILE
2	MODIFY EXISTING ARM DATA FILE
3	SPECIFY DETAILED GEOMETRY
4	TERMINATE ARM DEFINITION

ENTER INTEGER VALUE FOR MODE DESIRED

1

WHICH UNITS DO YOU WISH TO USE FOR I/O?
ENTER 1 FOR METRIC UNITS
ENTER 2 FOR ENGLISH UNITS

1

UNITS FOR INPUT/OUTPUT ARE AS FOLLOWS:

LENGTH	METERS
VELOCITY	METERS/SEC
ACCELERATION	METERS/S**2
MASS	KILOGRAMS
INERTIA	KG-M**2
FORCE	NEWTONS
TORQUE	N-M

**** ROBOT ARM DEFINITION ****

SPECIFY WHETHER GRAPHICS ARE DESIRED
DURING SYSTEM DEFINITION

**** NOTE **** YOU MUST HAVE ASSIGNED AN
EVANS AND SUTHERLAND WORK STATION
PRIOR TO RUNNING ROBSIM IN ORDER TO
REQUEST GRAPHICS

ENTER 1 FOR NO GRAPHICS
ENTER 2 FOR GRAPHICS

2

SPECIFY SPAN, OR REACH, OF ARM IN METERS

1.

SPECIFY X, Y, AND Z LOCATION OF BASE
IN WORLD COORDINATES. THE WORLD
COORDINATE SYSTEM IS DEFINED WITH
ORIGIN AT THE CENTER OF THE SCREEN
XW = POSITIVE TO THE RIGHT
YW = POSITIVE UPWARD
ZW = POSITIVE OUT OF THE SCREEN

ENTER BASE X LOCATION, IN METERS

0.

ENTER BASE Y LOCATION, IN METERS

0.

ENTER BASE Z LOCATION, IN METERS

0.

SPECIFY ROTATION SEQUENCE FOR ORIENTATION
OF BASE SYSTEM WITH RESPECT TO WORLD SYSTEM
SEQUENCE IS SPECIFIED BY A SERIES OF
ROTATION AXIS/ROTATION ANGLE PAIRS WHERE
1 REPRESENTS THE X AXIS
2 REPRESENTS THE Y AXIS
3 REPRESENTS THE Z AXIS
A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION

3

ENTER 1ST ROTATION ANGLE, IN DEGREES

90.

ENTER 1 TO SPECIFY ANOTHER ROTATION
ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT

2

SPECIFY ENDPOINTS OF BASE IN BASE COORDINATE
SYSTEM. CENTERLINE OF BASE IS ALONG X AXIS
SO ONLY X VALUES ARE REQUIRED

ENTER X COORDINATE FOR BOTTOM OF BASE, IN METERS
(SHOULD BE LESS THAN OR EQUAL TO ZERO)

0.

ENTER X COORDINATE FOR TOP OF BASE, IN METERS
(SHOULD BE GREATER THAN OR EQUAL TO DISTANCE
FROM BASE ORIGIN TO FIRST JOINT)

0.2

SPECIFY RADIUS AND NUMBER OF SIDES OF
BASE TO BE USED IN GRAPHIC REPRESENTATION

ENTER RADIUS OF BASE, IN METERS

0.05

ENTER NUMBER OF SIDES FOR BASE
MUST BE AN INTEGER FROM 3 TO 9

5

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO BEGIN JOINT/LINK DATA INPUT
ENTER 2 TO REDEFINE BASE

1

SPECIFICATION OF DATA DEFINING JOINT 1

SPECIFY JOINT TYPE

- 1 = HINGE JOINT (Y AXIS ROTATION)
- 2 = SWIVEL JOINT (X AXIS ROTATION)
- 3 = SLIDING JOINT (X AXIS TRANSLATION)

ENTER JOINT TYPE FOR JOINT 1

1

SPECIFY X, Y, AND Z LOCATION OF CURRENT JOINT
USING PREVIOUS JOINT COORDINATE SYSTEM

THE X AXIS IS DIRECTED FROM THE JOINT ALONG
THE CENTERLINE OF THE LINK BETWEEN THE PREVIOUS
JOINT AND THE CURRENT JOINT

THE YZ PLANE ORIENTATION IS USER DEFINED
NOTE THAT HINGE JOINTS ROTATE ABOUT THE Y AXIS
SWIVEL JOINTS ROTATE ABOUT THE X AXIS
AND SLIDING JOINTS MOVE ALONG THE X AXIS

0.2 ENTER X LOCATION OF JOINT 1 IN METERS
0. ENTER Y LOCATION OF JOINT 1 IN METERS
0. ENTER Z LOCATION OF JOINT 1 IN METERS
0.

SPECIFY ROTATION SEQUENCE FOR ORIENTATION
OF CURRENT JOINT WITH RESPECT TO PREVIOUS
JOINT.

SEQUENCE IS SPECIFIED BY A SERIES OF
ROTATION AXIS/ROTATION ANGLE PAIRS WHERE

1 REPRESENTS THE X AXIS
2 REPRESENTS THE Y AXIS
3 REPRESENTS THE Z AXIS
A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION
3

ENTER 1ST ROTATION ANGLE, IN DEGREES
-90.

ENTER 1 TO SPECIFY ANOTHER AXIS/ANGLE PAIR
ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT
2

SPECIFY INITIAL VALUE FOR CURRENT JOINT
VARIABLE. INITIAL ANGULAR ROTATION FOR
HINGE OR SWIVEL JOINTS, INITIAL LENGTH
FOR SLIDING JOINTS

ENTER INITIAL JOINT VARIABLE VALUE FOR JOINT 1
IN DEGREES FOR ANGULAR VALUE
IN METERS FOR LENGTH VALUE
0.

SPECIFY TRAVEL AND RATE LIMITS FOR CURRENT JOINT.
ENTER MINIMUM AND MAXIMUM ANGULAR ROTATION
POSSIBLE FOR HINGE OR SWIVEL JOINTS, MIN., MAX.
LENGTH FOR SLIDING JOINTS

ENTER MIN., MAX. TRAVEL LIMIT VALUES FOR JOINT 1
IN DEGREES FOR ANGULAR VALUE
IN METERS FOR LENGTH VALUE
-90., 90.

ENTER MAXIMUM RATE FOR JOINT 1
IN RADIANS/SEC FOR ANGULAR RATE
IN METERS/SEC FOR SLIDING JOINT
1.5

DEFINITION OF ACTUATOR FOR JOINT 1

DO YOU WISH TO DEFINE ACTUATOR PARAMETERS
FOR JOINT 1

- 1 INPUT INTERACTIVELY THE ACTUATOR PARAMETER VALUES
- 2 READ A FILE FOR PARAMETER VALUE DEFINITION
- 3 NO ACTUATOR PARAMETER DEFINITION FOR JOINT 1

2

ENTER FILENAME OF ACTUATOR PARAMETER FILE
TO BE READ. FILE MUST CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40

EXAMPLE - ROBDEVICE:[ROBDIR]PLANAR.ACT
PLANAR.ACT

DEFINITION OF LINK FROM JOINT 1 TO JOINT 2

SPECIFY END POINTS OF LINK BETWEEN JOINT 1
AND JOINT 2 IN JOINT 1 COORDINATE
SYSTEM. CENTERLINE OF LINK IS ALONG X AXIS
SO ONLY X VALUES ARE REQUIRED

ENTER X COORDINATE OF LINK BASE ENDPOINT,
IN METERS (SHOULD BE LESS THAN OR EQUAL TO ZERO)

0.

ENTER X COORDINATE OF LINK TOOL ENDPOINT, IN METERS
(SHOULD BE GREATER THAN OR EQUAL TO THE DISTANCE
FROM JOINT 1 TO JOINT 2)

0.45

SPECIFY RADIUS OF LINK BETWEEN JOINT 1 AND JOINT 2
TO BE USED IN GRAPHIC REPRESENTATION

ENTER RADIUS, IN METERS

0.07

SPECIFY NUMBER OF SIDES FOR LINK BETWEEN JOINT 1 AND JOINT 2
TO BE USED IN GRAPHIC REPRESENTATION

ENTER INTEGER NUMBER OF SIDES FROM 3 TO 9

7

SPECIFY CENTER OF MASS LOCATION BETWEEN JOINT 1
AND JOINT 2 IN JOINT 1 COORDINATE SYSTEM

ENTER 1 TO HAVE PROGRAM COMPUTE CENTER OF MASS
ENTER 2 TO REQUEST USER INPUT OF CENTER OF MASS

1

SPECIFY MASS OF LINK BETWEEN JOINT 1 AND JOINT 2

ENTER MASS, IN KILOGRAMS

5.108

SPECIFY INERTIA MATRIX FOR LINK BETWEEN JOINT 1 AND JOINT 2

ENTER 1 TO HAVE PROGRAM COMPUTE INERTIA MATRIX
ENTER 2 TO REQUEST USER INPUT OF INERTIA MATRIX

1

ENTER 1 TO SPECIFY POINT MASSES FOR LINK 1
ENTER 2 NOT TO SPECIFY POINT MASSES FOR LINK 1

2

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO DEFINE ANOTHER JOINT/LINK COMBINATION
ENTER 2 TO REDEFINE CURRENT JOINT/LINK
ENTER 3 TO BEGIN TOOL DATA INPUT

1

SPECIFICATION OF DATA DEFINING JOINT 2

SPECIFY JOINT TYPE
1 = HINGE JOINT (Y AXIS ROTATION)
2 = SWIVEL JOINT (X AXIS ROTATION)
3 = SLIDING JOINT (X AXIS TRANSLATION)
ENTER JOINT TYPE FOR JOINT 2

1

SPECIFY X, Y, AND Z LOCATION OF CURRENT JOINT
USING PREVIOUS JOINT COORDINATE SYSTEM
THE X AXIS IS DIRECTED FROM THE JOINT ALONG
THE CENTERLINE OF THE LINK BETWEEN THE PREVIOUS
JOINT AND THE CURRENT JOINT
THE YZ PLANE ORIENTATION IS USER DEFINED
NOTE THAT HINGE JOINTS ROTATE ABOUT THE Y AXIS
SWIVEL JOINTS ROTATE ABOUT THE X AXIS
AND SLIDING JOINTS MOVE ALONG THE X AXIS

ENTER X LOCATION OF JOINT 2 IN METERS
0.426

ENTER Y LOCATION OF JOINT 2 IN METERS
0.

ENTER Z LOCATION OF JOINT 2 IN METERS
0.

SPECIFY ROTATION SEQUENCE FOR ORIENTATION
OF CURRENT JOINT WITH RESPECT TO PREVIOUS
JOINT.

SEQUENCE IS SPECIFIED BY A SERIES OF
ROTATION AXIS/ROTATION ANGLE PAIRS WHERE

1 REPRESENTS THE X AXIS

2 REPRESENTS THE Y AXIS

3 REPRESENTS THE Z AXIS

A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION

1

ENTER 1ST ROTATION ANGLE, IN DEGREES

0.

ENTER 1 TO SPECIFY ANOTHER AXIS/ANGLE PAIR
ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT

2

SPECIFY INITIAL VALUE FOR CURRENT JOINT
VARIABLE. INITIAL ANGULAR ROTATION FOR
HINGE OR SWIVEL JOINTS, INITIAL LENGTH
FOR SLIDING JOINTS

ENTER INITIAL JOINT VARIABLE VALUE FOR JOINT 2
IN DEGREES FOR ANGULAR VALUE
IN METERS FOR LENGTH VALUE

0.

SPECIFY TRAVEL AND RATE LIMITS FOR CURRENT JOINT.
ENTER MINIMUM AND MAXIMUM ANGULAR ROTATION
POSSIBLE FOR HINGE OR SWIVEL JOINTS, MIN.,MAX.
LENGTH FOR SLIDING JOINTS

ENTER MIN.,MAX. TRAVEL LIMIT VALUES FOR JOINT 2
IN DEGREES FOR ANGULAR VALUE
IN METERS FOR LENGTH VALUE

-120.,120.

ENTER MAXIMUM RATE FOR JOINT 2
IN RADIANS/SEC FOR ANGULAR RATE
IN METERS/SEC FOR SLIDING JOINT

1.5

DEFINITION OF ACTUATOR FOR JOINT 2

DO YOU WISH TO DEFINE ACTUATOR PARAMETERS
FOR JOINT 2

1 INPUT INTERACTIVELY THE ACTUATOR PARAMETER VALUES

2 READ A FILE FOR PARAMETER VALUE DEFINITION

3 NO ACTUATOR PARAMETER DEFINITION FOR JOINT 2

2

ENTER FILENAME OF ACTUATOR PARAMETER FILE
TO BE READ. FILE MUST CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANAR.ACT
PLANAR.ACT

DEFINITION OF LINK FROM JOINT 2 TO JOINT 3

SPECIFY END POINTS OF LINK BETWEEN JOINT 2
AND JOINT 3 IN JOINT 2 COORDINATE
SYSTEM. CENTERLINE OF LINK IS ALONG X AXIS
SO ONLY X VALUES ARE REQUIRED

ENTER X COORDINATE OF LINK BASE ENDPOINT,
IN METERS (SHOULD BE LESS THAN OR EQUAL TO ZERO)

0.

ENTER X COORDINATE OF LINK TOOL ENDPOINT, IN METERS
(SHOULD BE GREATER THAN OR EQUAL TO THE DISTANCE
FROM JOINT 2 TO JOINT 3)

0.36

SPECIFY RADIUS OF LINK BETWEEN JOINT 2 AND JOINT 3
TO BE USED IN GRAPHIC REPRESENTATION

ENTER RADIUS, IN METERS

0.06

SPECIFY NUMBER OF SIDES FOR LINK BETWEEN JOINT 2 AND JOINT 3
TO BE USED IN GRAPHIC REPRESENTATION

ENTER INTEGER NUMBER OF SIDES FROM 3 TO 9

7

SPECIFY CENTER OF MASS LOCATION BETWEEN JOINT 2
AND JOINT 3 IN JOINT 2 COORDINATE SYSTEM

ENTER 1 TO HAVE PROGRAM COMPUTE CENTER OF MASS
ENTER 2 TO REQUEST USER INPUT OF CENTER OF MASS

1

SPECIFY MASS OF LINK BETWEEN JOINT 2 AND JOINT 3

ENTER MASS, IN KILOGRAMS

1.698

SPECIFY INERTIA MATRIX FOR LINK BETWEEN JOINT 2 AND JOINT 3

ENTER 1 TO HAVE PROGRAM COMPUTE INERTIA MATRIX
ENTER 2 TO REQUEST USER INPUT OF INERTIA MATRIX

1

ENTER 1 TO SPECIFY POINT MASSES FOR LINK 2
ENTER 2 NOT TO SPECIFY POINT MASSES FOR LINK 2

2

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO DEFINE ANOTHER JOINT/LINK COMBINATION
ENTER 2 TO REDEFINE CURRENT JOINT/LINK
ENTER 3 TO BEGIN TOOL DATA INPUT

3

DO YOU WISH ANY SPECIAL JOINTS?
ENTER 1 TO INCLUDE SPECIAL JOINTS
ENTER 2 FOR NO SPECIAL JOINTS

2

SPECIFY TOOL LOCATION AND ORIENTATION WITH
RESPECT TO FINAL JOINT

SPECIFY X, Y, AND Z LOCATION OF TOOL
IN FINAL JOINT COORDINATE SYSTEM

ENTER X LOCATION OF TOOL, IN METERS

0.348

ENTER Y LOCATION OF TOOL, IN METERS

0.

ENTER Z LOCATION OF TOOL, IN METERS

0.

SPECIFY ROTATION SEQUENCE FOR ORIENTATION
OF TOOL SYSTEM WITH RESPECT TO FINAL
JOINT SYSTEM.

SEQUENCE IS SPECIFIED BY A SERIES OF
ROTATION AXIS/ROTATION ANGLE PAIRS WHERE

1 REPRESENTS THE X AXIS

2 REPRESENTS THE Y AXIS

3 REPRESENTS THE Z AXIS

A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION

1

0. ENTER 1ST ROTATION ANGLE, IN DEGREES

ENTER 1 TO SPECIFY ANOTHER AXIS/ANGLE PAIR
 ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT

2

DEFINITION OF TOOL

SPECIFY END POINTS OF TOOL
 CENTERLINE OF LINK IS ALONG X AXIS
 SO ONLY X VALUES ARE REQUIRED

ENTER X COORDINATE OF TOOL BASE ENDPOINT,
 IN METERS (SHOULD BE LESS THAN OR EQUAL TO ZERO)

0.

ENTER X COORDINATE OF TOOL ENDPOINT, IN METERS

0.1

SPECIFY RADIUS OF TOOL
 TO BE USED IN GRAPHIC REPRESENTATION

ENTER RADIUS, IN METERS

0.3

SPECIFY NUMBER OF SIDES FOR TOOL
 TO BE USED IN GRAPHIC REPRESENTATION

ENTER INTEGER NUMBER OF SIDES FROM 3 TO 9

8

SPECIFY CENTER OF MASS LOCATION OF TOOL
 IN TOOL COORDINATE SYSTEM

ENTER 1 TO HAVE PROGRAM COMPUTE CENTER OF MASS
 ENTER 2 TO REQUEST USER INPUT OF CENTER OF MASS

1

SPECIFY MASS OF TOOL

ENTER MASS, IN KILOGRAMS

0.

SPECIFY INERTIA MATRIX FOR TOOL

ENTER 1 TO HAVE PROGRAM COMPUTE INERTIA MATRIX
 ENTER 2 TO REQUEST USER INPUT OF INERTIA MATRIX

1

ENTER 1 TO SPECIFY POINT MASSES FOR TOOL
 ENTER 2 NOT TO SPECIFY POINT MASSES FOR TOOL

2

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CONTINUE
ENTER 2 TO REDEFINE TOOL DATA

1

ENTER 1 TO CONTINUE
ENTER 2 TO MODIFY ARM DATA

1

ENTER RETURN TO TERMINATE GRAPHICS AND CONTINUE

<CR>

DO YOU WISH DETAILED ARM GEOMETRY?
1 NO DETAILED GEOMETRY
2 INCLUDE DETAILED GEOMETRY

1

ENTER FILENAME OF ARM DATA FILE
TO BE CREATED. FILE MUST NOT CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40

EXAMPLE - ROBDEVICE:[ROBDIR]PLANOUT.ARM
PLANAR.ARM

DO YOU WISH A PRINTOUT OF USER INPUT ARM GEOMETRY/
DESCRIPTION PARAMETER VALUES?

0 FOR NO ARM DESCRIPTION PRINTOUT
1 FOR A PRINTOUT OF ARM PARAMETER VALUES INPUT

1

ENTER FILENAME OF ARM GEOMETRY FILE
TO BE GENERATED FOR DATA PRINTOUT.
FILE MUST NOT CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40

EXAMPLE - ROBDEVICE:[ROBDIR]PLANAR.AGF
PLANAR.AGF

ARM DATA FILE HAS BEEN WRITTEN
ALL COMMON BLOCKS ARE SAVED

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE/MODIFY ARM DATA FILE
2	CREATE/MODIFY DETAILED ENVIRONMENT
3	CREATE/MODIFY LOAD OBJECTS FILE
4	CREATE SYSTEM DATA FILE
5	TERMINATE SYSTEM DEFINITION EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

5

EXITING FROM SYSTEM DEFINITION FUNCTION

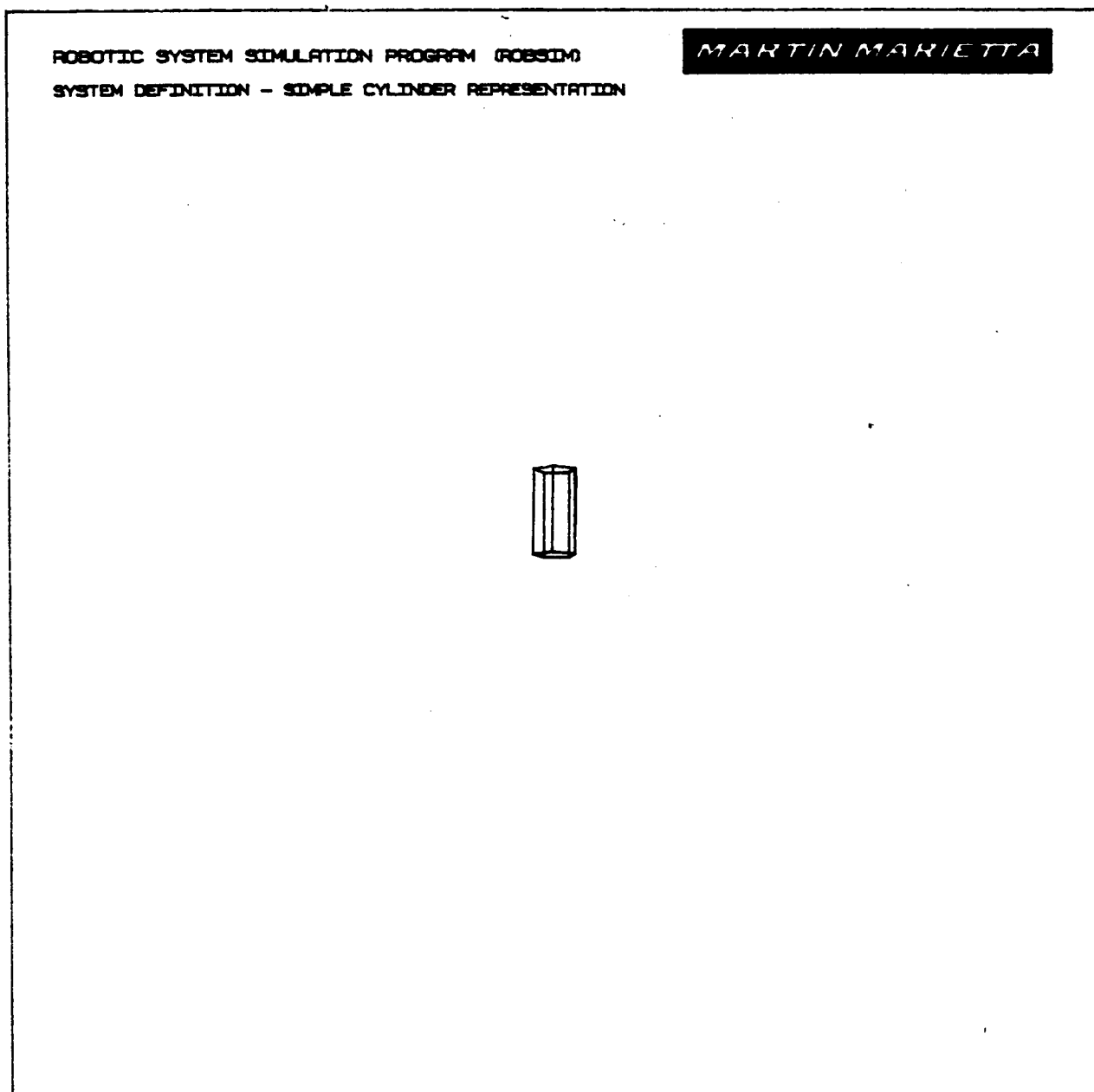


Figure A-2. - Simple cylinder base component.

ROBOTIC SYSTEM SIMULATION PROGRAM (ROSSIM)
SYSTEM DEFINITION - SIMPLE CYLINDER REPRESENTATION

MARTIN MARIETTA

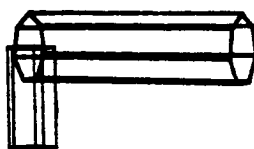


Figure A-3. - Simple cylinder base and first link.

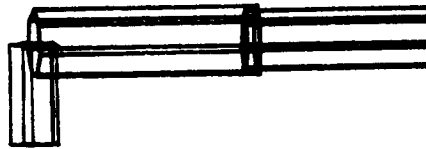


Figure A-4. - Simple cylinder base and links.



Figure A-5. - Complete simple cylinder planar arm.

ROBOTIC SYSTEM SIMULATION PROGRAM (ROSSIM)
SYSTEM DEFINITION - SIMPLE CYLINDER REPRESENTATION

MARTIN MARIETTA

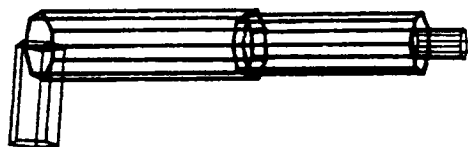


Figure A-6. - X-translation test for simple cylinder arm.

After all displayed components are termed complete, the entry to the terminal for halting the arm generation graphics display and termination of the Evans and Sutherland device unit is:

ENTER RETURN TO TERMINATE GRAPHICS AND CONTINUE

Also, a user directed question to automatically include a detailed graphics representation for the arm input via the arm creation routine will be advanced. If the answer is to undertake this mode, then detailed geometry component definition procedure will commence immediately. This allows a more elaborate description of the manipulator arm links to be input. The request is given by the prompt:

DO YOU WISH DETAILED ARM GEOMETRY?

- 1 NO DETAILED GEOMETRY
- 2 INCLUDE DETAILED GEOMETRY

The methodology of detailed graphics production is capitalized in the section below.

Procedure for creating a detailed robot arm geometry. - There are sub-routines provided giving the user the capability to specify a more elaborate physical representation for the links of the robotic arm that can detail the geometry of real hardware and replace a simple cylinder arm. Components of the robotic arm are defined by combinations of geometric primitives. A number of detailed components can be included for the base, each link extension and the tool definitions. Combinations of these primitives are used to build more accurate arm models.

The components are simple three-dimensional geometric shapes. The user is requested to input the geometric dimensions of the specific shape. Additional shapes may be added as required. Subroutines are provided to calculate the data points for each requested shape. Other program input routines are called to position and orient the components relative to the appropriate robotic arm base, joint or tool frame. The components are drawn with the graphics package. The new detailed robot arm data is added to the database describing the robot manipulator. These routines do not allow modification of detailed components after such a component has been saved in the arm object data array COMMON block. Care must be exercised while entering a detailed description because only the most recently defined component of the detailed geometry may be modified and overwritten without total respecification of the detail beginning with the simple cylinder data file.

The joint and tool locations input during the simple cylinder arm creation session are preserved as the value for the detailed arm also. These joint placements are the key to success when planning the detailed components' locations and orientations.

The component shapes are selected and user interaction is as follows for each base, link or tool component propagation:

```
SELECT SHAPE
  1 = CYLINDER
  2 = CONE
  3 = RECTANGULAR SOLID
  4 = SYM TRAPEZOID
  5 = NONSYM TRAPEZOID
  6 = TRIANGULAR STRUCTURE
  7 = DATA TABLET STRUCTURE
  8 = FILLET
  9 = NONPLANAR ENTITY
ENTER INTEGER CHOICE
```

Upon choosing one of these component shapes, the corresponding sequence of inputs are as described under the categories sketched later, steps A) through F). These subsections are also applicable to the detailed definitions of components when following the Procedure for Creating a System Work Cell Environment or the detailed option under Procedure for Creating a Load Objects File.

The process for orientation of all detailed graphics components within the system definition function, during detailed representation generation for the environment, robotic arm or loads, occurs at the beginning of each individual component depiction. To position the current component properly in the reference coordinate system as it is displayed, the prompts are:

```
ENTER 1 IF ROTATIONS REQUIRED
ENTER 2 IF TRANSLATION ONLY
```

and for a rotation to be applied to the detailed part:

```
ENTER AXIS OF ROTATION
  1 = X-AXIS
  2 = Y-AXIS
  3 = Z-AXIS
```

```
ENTER ROTATION ANGLE, IN DEGREES
```

and after each rotation angle input:

```
ENTER 1 TO SPECIFY ANOTHER ROTATION
ENTER 2 TO TERMINATE ROTATION INPUT
```

and for translating the component to the correct location:

```
ENTER X,Y,Z TRANSLATION IN [length units]
```

Each shape will be eventually figured in the world coordinate system with a total transformation matrix. The component's points data array is loaded with these transformed values. The distance and rotation questions for the entity are with respect to the base, joint or tool-joint coordinate system corresponding to the current constituent. Each successive component is graphically displayed as defined and placed in its initialized state, with the base/link/tool transformation matrices concatenated to the inertial system.

Again the user will have the freedom to arrange the display using the Evans and Sutherland extended analog dials device for analyzing the component interlocks at a variety of perspectives. Function key 31 then allows the user to resume with another component definition or redefinition of the current component, if desired.

The current component of the current link is the only part that may be modified. The user is offered a chance to redefine the shape if it was incorrectly modelled with a response of 1 to the inquiry:

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

A maximum number of components are allowed to be included in any one joint/link representation. When the link has been accurately portrayed with a set of these components, enter a 2 for the question:

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO GO TO NEXT JOINT/LINK
ENTER 3 TO SAVE FILE AND EXIT

Otherwise the link is not complete, and the user will be required to input another shape dimension integer selection and the respective shape dimensions.

After all link component inputs and at the terminal point of the arm, if graphics has been elected the user should depress the RETURN key to write the new data to file and return to the arm building creation routine.

Sample run. - A series of detailed graphics pictures (Fig. A-7 through A-17) taken during an effort to model the Martin Marietta 3-link planar arm are included here, along with part of the interactive conversation required for generation, supplied in Example A-4. The base components were built with this included interactive run, and the representations for the rest of the joints/links and tool were similarly produced.

For instance, the robotic arm base includes the following constituent components:

1) Rectangular solid - This component has a length of 0.00635 meter along the individual component +x-axis, a width in the component +y-axis of 0.1524 meter and a width in the component +z-axis of 0.1524 meter. It is not rotated or translated with respect to the base coordinate system;

2) Rectangular solid - The second component has a length of 0.254 meter along the individual component +x-axis, a width of 0.0889 meter in the component +y-axis and +z-axis. It is not rotated with respect to the base reference system, but is translated 0.00635 meter along the x-axis of the base coordinate system;

3) Cylinder - The third component for the base has a diameter of 0.1397 meter in the component y-axis and z-axis directions. Its length along the component x-axis extends from the component origin ($x=0$) to 0.0714 meter. The cylinder is not rotated with respect to the base reference frame. It is translated 0.26 meter from the base location in the x-direction;

4) Rectangular solid - The last component for the detailed description of the manipulator base has a length of 0.0508 meter in the component x-axis extending from the component origin location in the positive x-direction. Again, the widths are given by 0.111125 in $\pm y$ and 0.0635 in $\pm z$ in the component reference frame. This part is translated 0.3318 meter in x and -0.047625 in y from the base reference location.

Example A-4

ROBOTIC SYSTEM SIMULATION PROGRAM (ROBSIM)

ENTERING SYSTEM DEFINITION FUNCTION

DEFAULT LOGICAL UNIT ASSIGNMENTS USED WITHIN ROBSIM

LU	USE
5	READ UNIT (TERMINAL)
6	WRITE UNIT (TERMINAL)
7	PRINTED OUTPUT UNIT
8-9	SIMULATION INPUT FILE
10	SIMULATION OUTPUT FILE
11	ACTUATOR PARAMETERS INPUT FILE
14	LOAD OBJECTS DATA FILE
15	ERROR MESSAGE FILE
16	GAIN CONSTANTS FILE
17	TORQUE DATA INPUT FILE
18	ACC-VEL-THETA FILE
19	PROGRAMS OPTIONS FILE
20	PLOT DATA FILE
21	MOTION TIME HISTORY FILE
22	HARDWARE CONTROL SIGNALS
23	CONTROL OPTIONS INPUT FILE
24	CONTROL MODULE OUTPUT FILE

USER WILL BE PROMPTED FOR FILENAMES
TO ASSOCIATE WITH EACH LOGICAL UNIT
WHEN REQUIRED

ENTER RETURN TO CONTINUE

<CR>

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE/MODIFY ARM DATA FILE
2	CREATE/MODIFY DETAILED ENVIRONMENT
3	CREATE/MODIFY LOAD OBJECTS FILE
4	CREATE SYSTEM DATA FILE
5	TERMINATE SYSTEM DEFINITION EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

1

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE ARM DATA FILE
2	MODIFY EXISTING ARM DATA FILE
3	SPECIFY DETAILED GEOMETRY
4	TERMINATE ARM DEFINITION

ENTER INTEGER VALUE FOR MODE DESIRED

3

ENTER FILENAME OF ARM DATA FILE
TO BE MODIFIED
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40

EXAMPLE - ROBDEVICE:[ROBDIR]PLANIN.ARM
PLANAR.ARM

ARM DATA FILE HAS BEEN READ
ALL COMMON BLOCKS ARE LOADED

SPECIFY DESIRED DISPOSITION OF
ARM DATA FILE

ENTER 1 TO SAVE FILE FOR FUTURE USE
ENTER 2 TO DELETE FILE

1

DEFINITION OF DETAILED GRAPHICS FOR LINK 1
(NOTE: LINK 1 DENOTES THE BASE)

SELECT SHAPE

1 = CYLINDER
2 = CONE
3 = RECTANGULAR SOLID
4 = SYM TRAPEZOID
5 = NONSYM TRAPEZOID
6 = TRIANGULAR STRUCTURE
7 = DATA TABLET STRUCTURE
8 = FILLET
9 = NONPLANAR ENTITY

ENTER INTEGER CHOICE

3

ENTER LENGTH (X) IN METERS
0.00635

ENTER Y (WIDTH IS +/-Y) IN METERS
0.1524

ENTER Z (BASE IS +/-Z) IN METERS
0.1524

ENTER 1 IF ROTATIONS REQUIRED
ENTER 2 IF TRANSLATION ONLY

2

ENTER X,Y,Z TRANSLATION IN METERS
0.,0.,0.

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

2

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO GO TO NEXT JOINT/LINK
ENTER 3 TO SAVE FILE AND EXIT

1

DEFINITION OF DETAILED GRAPHICS FOR LINK 1
(NOTE: LINK 1 DENOTES THE BASE)

SELECT SHAPE
1 = CYLINDER
2 = CONE
3 = RECTANGULAR SOLID
4 = SYM TRAPEZOID
5 = NONSYM TRAPEZOID
6 = TRIANGULAR STRUCTURE
7 = DATA TABLET STRUCTURE
8 = FILLET
9 = NONPLANAR ENTITY
ENTER INTEGER CHOICE

3

ENTER LENGTH (X) IN METERS
0.254

ENTER Y (WIDTH IS +/-Y) IN METERS
0.0889

ENTER Z (BASE IS +/-Z) IN METERS
0.0889

ENTER 1 IF ROTATIONS REQUIRED
ENTER 2 IF TRANSLATION ONLY

2

ENTER X,Y,Z TRANSLATION IN METERS
0.00635,0.,0.

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

2

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO GO TO NEXT JOINT/LINK
ENTER 3 TO SAVE FILE AND EXIT

1

DEFINITION OF DETAILED GRAPHICS FOR LINK 1
(NOTE: LINK 1 DENOTES THE BASE)

SELECT SHAPE
1 = CYLINDER
2 = CONE
3 = RECTANGULAR SOLID
4 = SYM TRAPEZOID
5 = NONSYM TRAPEZOID
6 = TRIANGULAR STRUCTURE
7 = DATA TABLET STRUCTURE
8 = FILLET
9 = NONPLANAR ENTITY
ENTER INTEGER CHOICE

1

ENTER DIAMETER IN METERS
0.1397

ENTER LENGTH IN METERS
0.0714

ENTER 1 IF ROTATIONS REQUIRED
ENTER 2 IF TRANSLATION ONLY

2

ENTER X,Y,Z TRANSLATION IN METERS
0.26,0.,0.

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***

ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

2

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO GO TO NEXT JOINT/LINK
ENTER 3 TO SAVE FILE AND EXIT

1

DEFINITION OF DETAILED GRAPHICS FOR LINK 1
(NOTE: LINK 1 DENOTES THE BASE)

SELECT SHAPE

- 1 = CYLINDER
- 2 = CONE
- 3 = RECTANGULAR SOLID
- 4 = SYM TRAPEZOID
- 5 = NONSYM TRAPEZOID
- 6 = TRIANGULAR STRUCTURE
- 7 = DATA TABLET STRUCTURE
- 8 = FILLET
- 9 = NONPLANAR ENTITY

ENTER INTEGER CHOICE

3

ENTER LENGTH (X) IN METERS
0.0508

ENTER Y (WIDTH IS +/-Y) IN METERS
0.111125

ENTER Z (BASE IS +/-Z) IN METERS
0.0635

ENTER 1 IF ROTATIONS REQUIRED
ENTER 2 IF TRANSLATION ONLY

2

ENTER X,Y,Z TRANSLATION IN METERS
0.3318,-0.047625,0.

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***

ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

2

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO GO TO NEXT JOINT/LINK
ENTER 3 TO SAVE FILE AND EXIT

2

DEFINITION OF DETAILED GRAPHICS FOR LINK 2
(NOTE: LINK 1 DENOTES THE BASE)

SELECT SHAPE

1 = CYLINDER

2 = CONE

3 = RECTANGULAR SOLID

4 = SYM TRAPEZOID

5 = NONSYM TRAPEZOID

6 = TRIANGULAR STRUCTURE

7 = DATA TABLET STRUCTURE

8 = FILLET

9 = NONPLANAR ENTITY

ENTER INTEGER CHOICE

o

o

o

ROBOTIC SYSTEM SIMULATION PROGRAM (ROSSIM)
SYSTEM DEFINITION - DETAILED GEOMETRY REPRESENTATION

MARTIN MARIETTA



Figure A-7. - First component in detailed arm base.

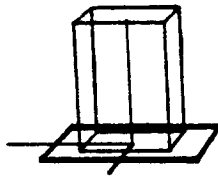


Figure A-8. - First two components in detailed arm base.

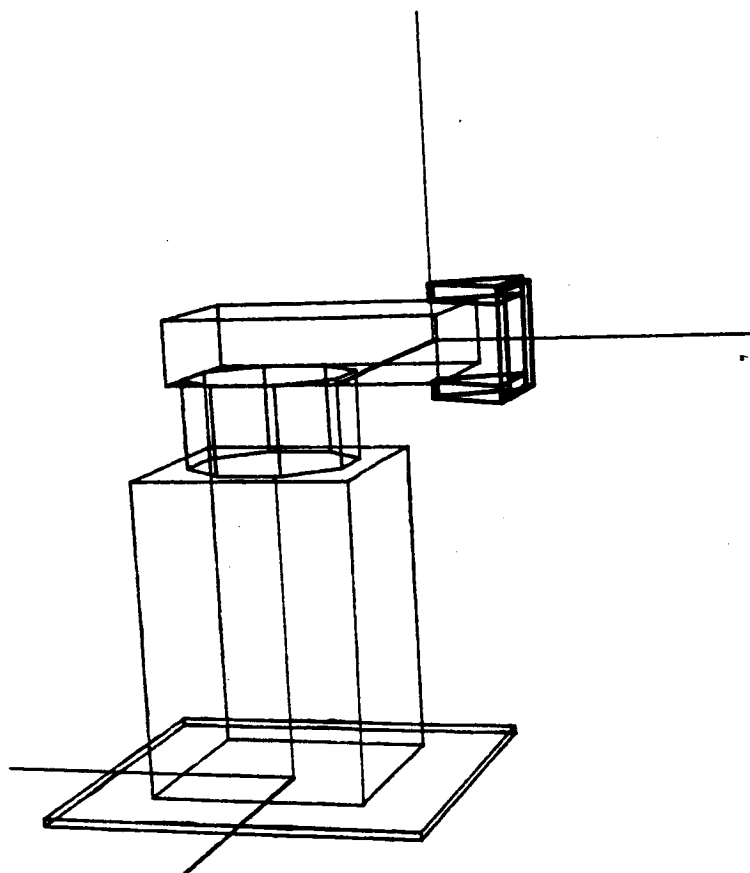


Figure A-9. - Beginnining joint 1 in detailed arm components.

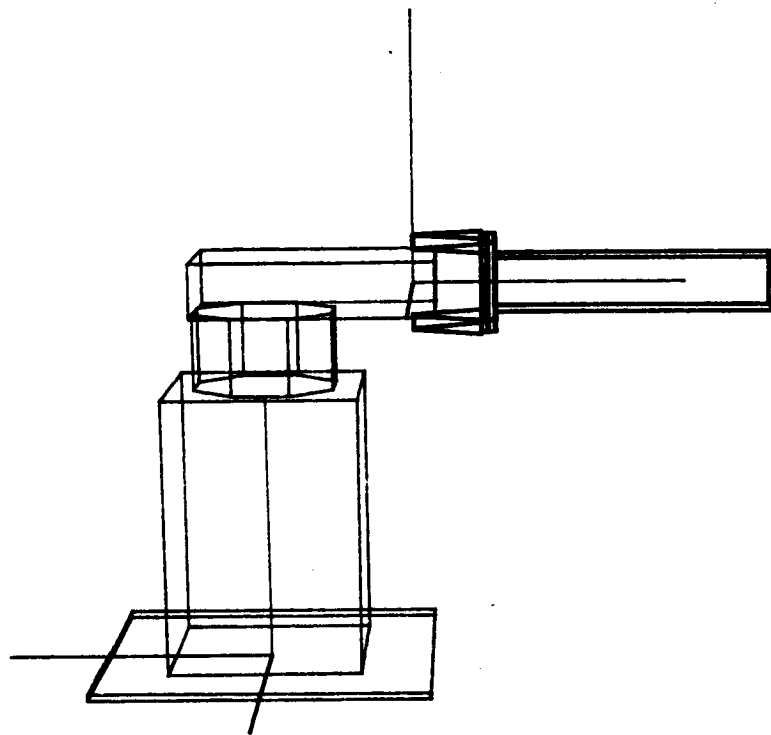


Figure A-10. - Generation of link 1 in detail arm.

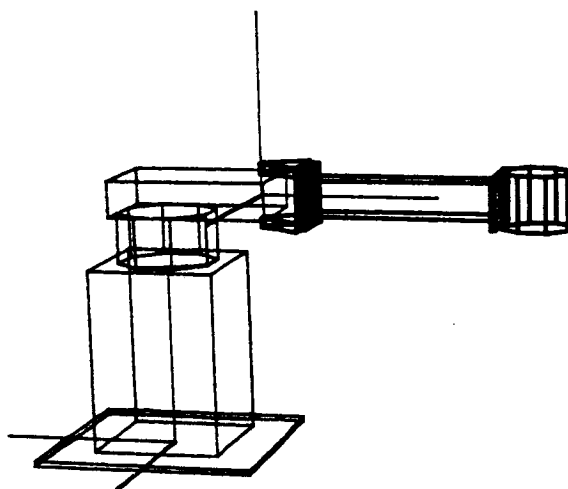


Figure A-11. - Completion of base and link 1 in detail arm.

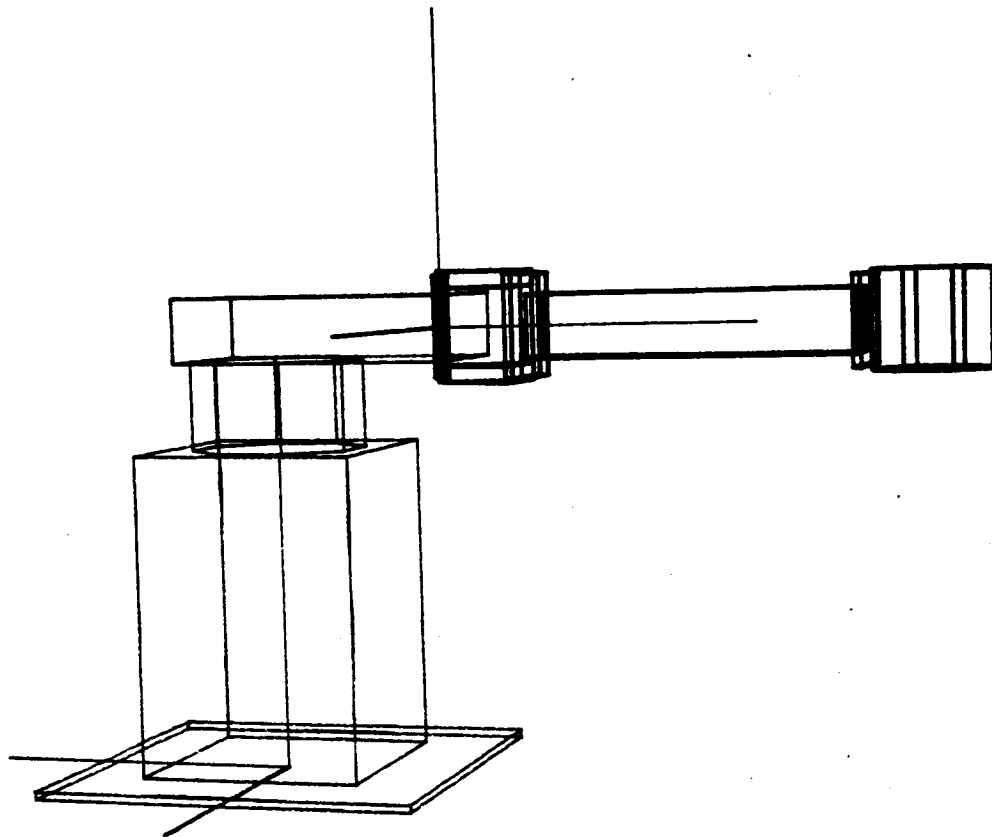


Figure A-12. - Zoom perspective of base and link 1 of detail arm.

ROBOTIC SYSTEM SIMULATION PROGRAM (ROSSIM)
SYSTEM DEFINITION - DETAILED GEOMETRY REPRESENTATION

MARTIN MARIETTA

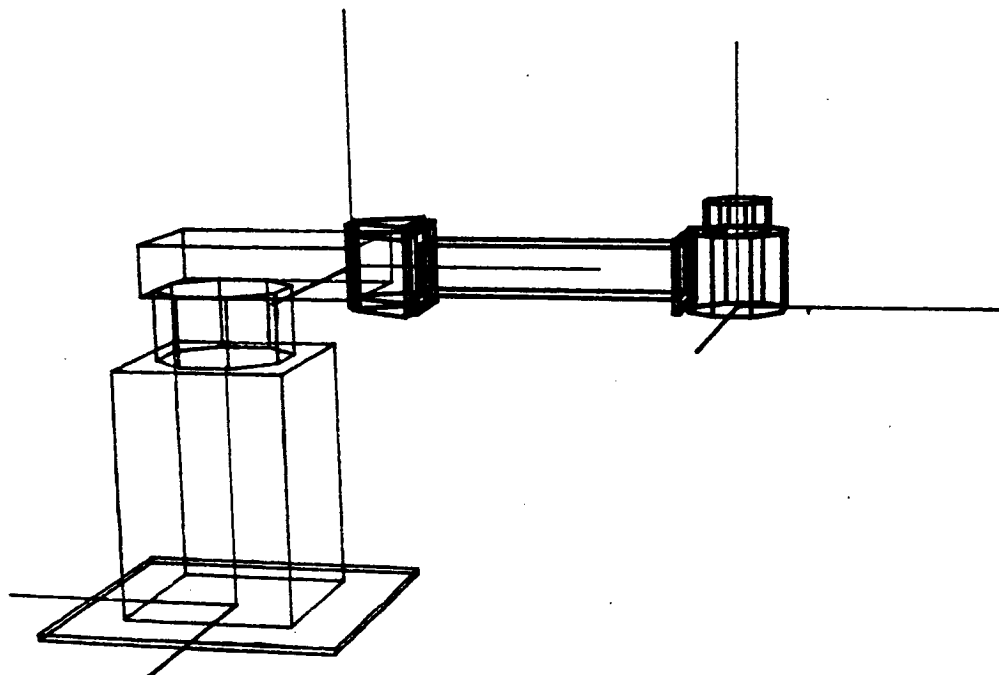


Figure A-13. - Erroneous component entry during joint 2 of detail arm.

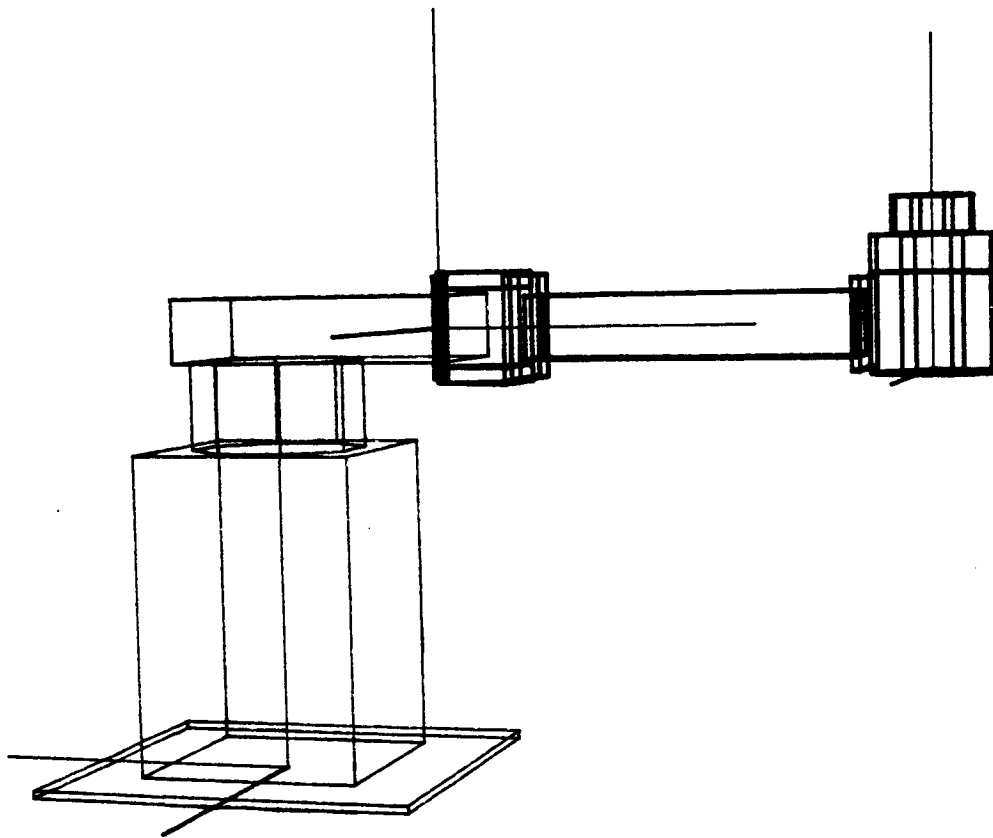


Figure A-14. -
First two components of joint 2 in detail arm after correction.

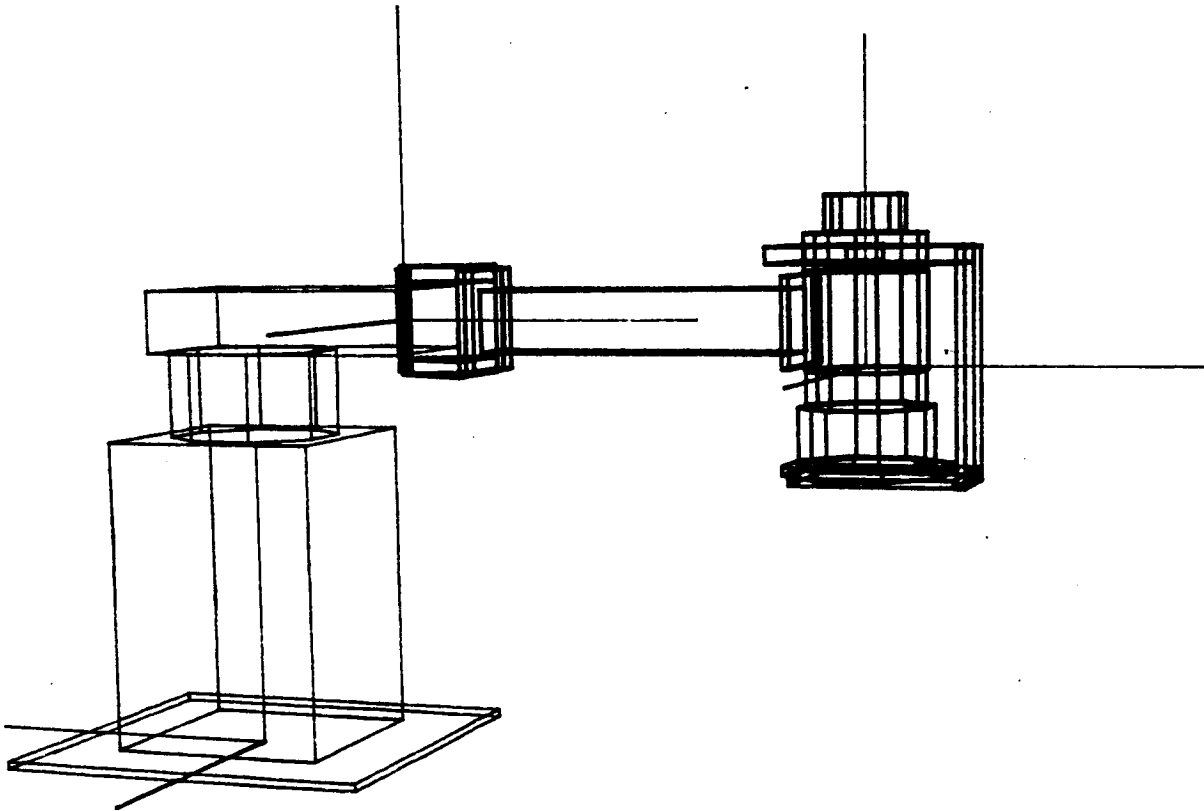


Figure A-15. - Completion of joint 2 in detailed arm.

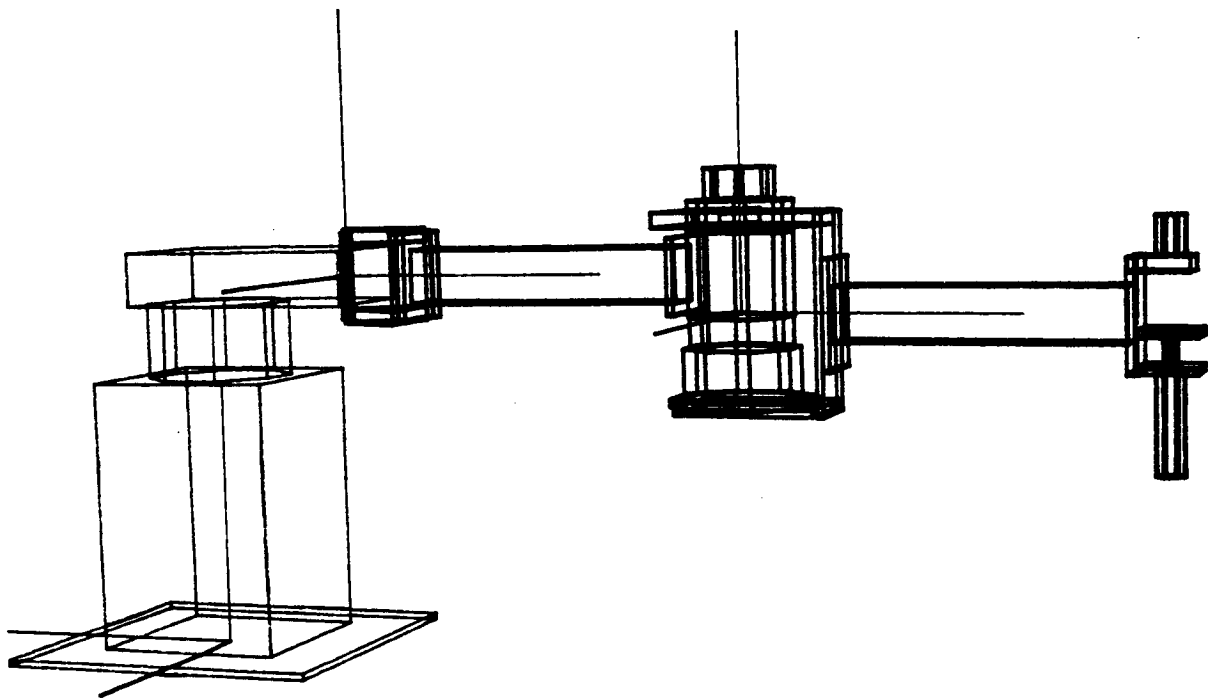


Figure A-16. - Completion of base, link 1 and 2 of detailed arm.

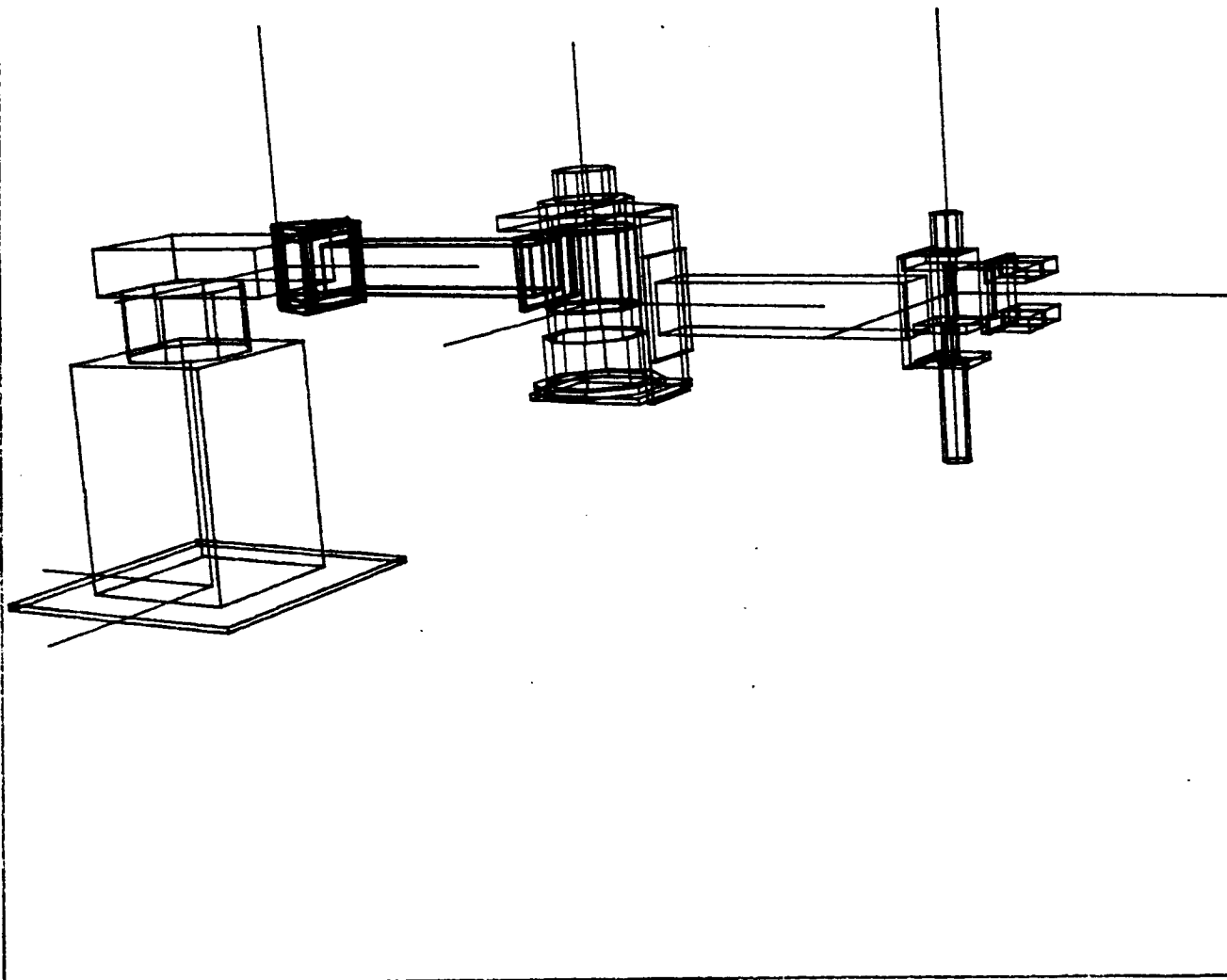


Figure A-17. - Complete detailed planar arm.

The conversation appearing at the end of any arm building session is as follows. The contents of the robotic arm that is saved on file after definition are the pertinent COMMON blocks describing the robotic arm geometry, mass properties and graphics description. The user is prompted for the file name (usually appended with '.ARM') under which the file is to be stored:

```
ENTER FILENAME OF ARM DATA FILE
TO BE CREATED. FILE MUST NOT CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANOUT.ARM
```

This is the arm ('.ARM') file that the user will enter into a robotic system scenario.

Option for a printout describing the robotic arm geometry is also implemented. To receive a copy of the Arm Geometry ('.AGF') file, answer 1 to:

```
DO YOU WISH A PRINTOUT OF USER INPUT ARM GEOMETRY/
DESCRIPTION PARAMETER VALUES?
0 FOR NO ARM DESCRIPTION PRINTOUT
1 FOR A PRINTOUT OF ARM PARAMETER VALUES INPUT
```

and, if opting for the printout file of the user inputs during the arm geometry definition session, input the file name in which to store the printout:

```
ENTER FILENAME OF ARM GEOMETRY FILE
TO BE GENERATED FOR DATA PRINTOUT.
FILE MUST NOT CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANAR.AGF
```

An example printout of the arm geometry file follows.

Example of Arm Geometry File Printout

***** PLANAR.AGF

***** INPUT ARM GEOMETRY DESCRIPTION *****

NUMBER OF JOINTS, NJ 2
MANIPULATOR ARM SPAN, OR REACH, ARMSPN 0.10000E+01

BASE DATA :

BASE LOCATION, AJTLOC 0.00000E+00 0.00000E+00 0.00000E+00
ORIENTATION, OR -0.43711E-07 0.10000E+01 0.00000E+00
-0.10000E+01 -0.43711E-07 0.00000E+00
0.00000E+00 0.00000E+00 0.10000E+01
ROTATION SEQUENCE, JNTSEQ 300
ROTATION ANGLES, AJTANG 0.90000E+02 0.00000E+00 0.00000E+00
BASE END POINTS, ENDPTS 0.00000E+00 0.20000E+00
NUMBER OF SIDES OF BASE, NSDLNK 5
BASE RADIUS, ALKRAD 0.50000E-01

JOINT 1 DATA :

JOINT TYPE, JNTTYP(1) 1
INITIAL VALUES, AJTVAR(1) 0.00000E+00
TRAVEL LIMIT, TRVLMT(1) -0.15708E+01 0.15708E+01
JOINT LOCATION, AJTLOC(2) 0.20000E+00 0.00000E+00 0.00000E+00
ORIENTATION, OR(2) -0.43711E-07 -0.10000E+01 0.00000E+00
0.10000E+01 -0.43711E-07 0.00000E+00
0.00000E+00 0.00000E+00 0.10000E+01
ROTATION SEQUENCES, JNTSEQ(2) 300
ROTATION ANGLES, AJTANG(2) -0.90000E+02 0.00000E+00 0.00000E+00
ENDPOINTS, ENDPTS(2) 0.00000E+00 0.45000E+00
NUMBER OF SIDES, NSDLNK(2) 7
RADIUS OF LINK, ALKRAD(2) 0.70000E-01
LINK MASS, ALKMAS(2), IN KILOGRAMS 0.51080E+01

MOTOR TORQUE CONSTANT, TORKI(1) 0.3584000111E+01
MOTOR WINDING RESISTANCE, ARMRA(1) 0.2799999952E+01
GEAR RATIO, GRATN(1) 0.2025000000E+02
AMPLIFIER GAIN, AMPGA(1) 0.1000000000E+02
COULOMB FRICTION COEFF, CFCOEF(1) 0.4390000105E+00
STATIC FRICTION COEFFICIENT, FCOEF(1) 0.6159999967E+00
MOTOR WINDING INDUCTANCE, ARMLA(1) 0.9999999747E-04
MOTOR BACK EMF, EMFKB(1) 0.3584000111E+01
EFFECTIVE INERTIA, EFFJT(1) 0.8929999918E-01
EFFECTIVE VISCOUS DAMPING, EFFKT(1) 0.8775000274E-01

JOINT 2 DATA :

```

JOINT TYPE, JNTTYP( 2) 1
INITIAL VALUES, AJTVAR( 2) 0.00000E+00
TRAVEL LIMIT, TRVLMT( 2) -0.20944E+01 0.20944E+01
JOINT LOCATION, AJTLOC( 3) 0.42600E+00 0.00000E+00 0.00000E+00
ORIENTATION, OR( 3) 0.10000E+01 0.00000E+00 0.00000E+00
0.00000E+00 0.10000E+01 0.00000E+00
0.00000E+00 0.00000E+00 0.10000E+01
ROTATION SEQUENCES, JNTSEQ( 3) 100
ROTATION ANGLES, AJTANG( 3) 0.00000E+00 0.00000E+00 0.00000E+00
ENDPOINTS, ENDPTS( 3) 0.00000E+00 0.36000E+00
NUMBER OF SIDES, NSDLNK( 3) 7
RADIUS OF LINK, ALKRAD( 3) 0.60000E-01
LINK MASS, ALKMAS( 3), IN KILOGRAMS 0.16980E+01

MOTOR TORQUE CONSTANT, TORKI( 2) 0.2851199913E+02
MOTOR WINDING RESISTANCE, ARMRA( 2) 0.5000000000E+01
GEAR RATIO, GRATN( 2) 0.8640000153E+02
AMPLIFIER GAIN, AMPGA( 2) 0.1500000000E+02
COULOMB FRICTION COEFF, CFCEFF( 2) 0.1360000014E+01
STATIC FRICTION COEFFICIENT, FCOEF( 2) 0.2039999962E+01
MOTOR WINDING INDUCTANCE, ARMLA( 2) 0.1899999939E-01
MOTOR BACK EMF, EMFKB( 2) 0.2851199913E+02
EFFECTIVE INERTIA, EFFJT( 2) 0.6769999862E+00
EFFECTIVE VISCOUS DAMPING, EFFKT( 2) 0.1134999990E+01

```

TOOL DATA :

```

TOOL LOCATION, AJTLOC 0.34800E+00 0.00000E+00 0.00000E+00
ORIENTATION, OR 0.10000E+01 0.00000E+00 0.00000E+00
0.00000E+00 0.10000E+01 0.00000E+00
0.00000E+00 0.00000E+00 0.10000E+01
ROTATION SEQUENCE, JNTSEQ 100
ROTATION ANGLES, AJTANG 0.00000E+00 0.00000E+00 0.00000E+00
TOOL END POINTS, ENDPTS 0.00000E+00 0.10000E+00
NUMBER OF SIDES OF TOOL, NSDLNK 8
TOOL RADIUS, ALKRAD 0.30000E-01
TOOL MASS, ALKMAS, IN KILOGRAMS 0.00000E+00

```

Most of the explanations of the output variables may be decoded from the printout example. For further information refer to the ROBSIM programmer's guide.

A) Cylindrical and cone-shaped entities. - The system definition function option to create detailed components parameterizing cone shaped or cylindrical forms is described here. These shapes are included during detailed graphic representation generation for any of the robotic system constituents (environment, arms, loads). The input values for the shape dimensions are used to fashion the data points that circumscribe the shape.

For cylinders, these input elements are:

ENTER DIAMETER IN [length units]

and

ENTER LENGTH IN [length units]

For cone components the user needs to specify:

ENTER DIAMETER IN [length units]

and

ENTER TOP DIAMETER OF CONE IN [length units]

and

ENTER LENGTH IN [length units]

This input should be in the user-opted I/O units of length (meters or inches). For the diameters and lengths, the data defining the shape are computed in a shape coordinate system. The x-axis is along the shape centerline and the shape length is measured from $x=0$ to $x=\text{the cylinder length}$. The vertex points of the displayed cylinder or cone are computed standardly with 8 sides and the shape diameters input. The data points will be loaded into an array as Cartesian coordinates in the shape coordinate system. Figure A-18 symbolizes the cylinder and the cone components. In this figure the dimensions are denoted with the symbols:

DIAM1 = Diameter of cone bottom and cylinder diameter

DIAM2 = Diameter of top of cone

CLEN = Length of cone/cylinder

B) Rectangular and trapezoidal entities. - Within the system definition generation of detailed graphic representations for environment, arm or load objects files the following values are input by the user to describe rectangular solids, symmetric trapezoidal and nonsymmetric trapezoidal solid figures.

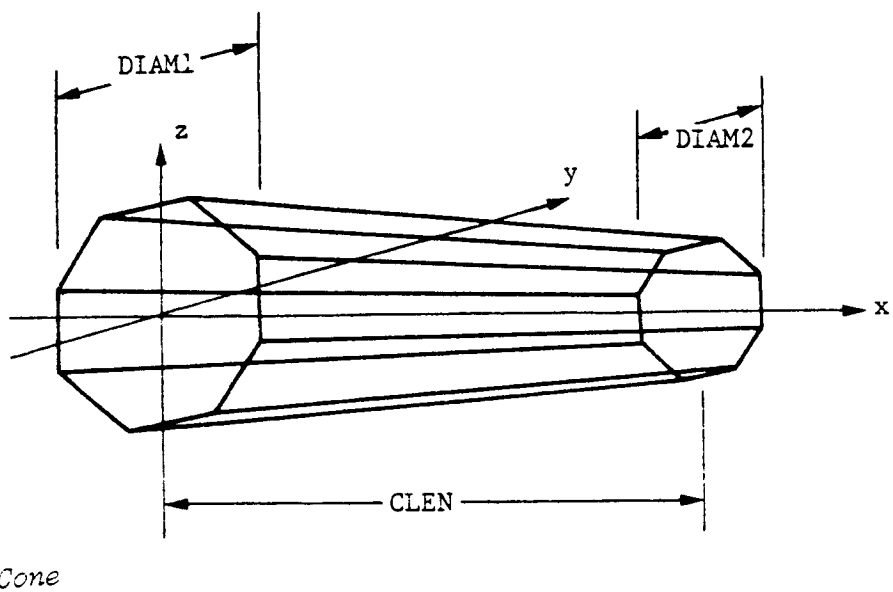
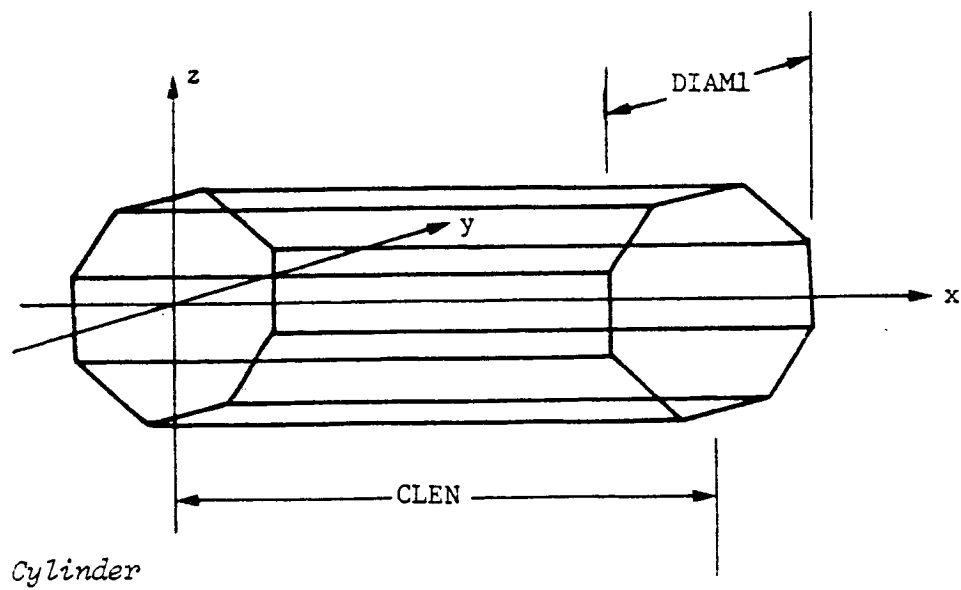


Figure A-18. - Cylinder and cone shape coordinate system.

For rectangular solid components, input in the predefined I/O units:

ENTER LENGTH (X) IN [length units]

ENTER Y (WIDTH IS +/-Y) IN [length units]

ENTER Z (BASE IS +/-Z) IN [length units]

For symmetric or nonsymmetric trapezoidal components:

ENTER LENGTH (X) IN [length units]

ENTER Y (WIDTH IS +/-Y) IN [length units]

and the first and second base of the trapezoid:

ENTER Z1 IN [length units]

ENTER Z2 IN [length units]

For these rectangles and trapezoids, the points that describe the figure are computed and loaded into the graphics array for the display. The x-axis is along the shape centerline and the shape length is measured from $x=0$ to $x=\text{the input length (X0)}$. The rectangle and symmetric trapezoid are symmetric about both the y and z axes. For symmetric trapezoids, the z dimension equals $2*Z1$ along the entire figure. The non-symmetric trapezoid is symmetric about the y-axis but the z-axis dimensions are measured from $z=0$ to $z=Z2$ at the $x=X0$ end. The vertex points are computed corresponding to the dimensions input, and the data points are stored in an array as Cartesian coordinates in the shape coordinate system (Figure A-19). The following equivalent terms are used in these figures:

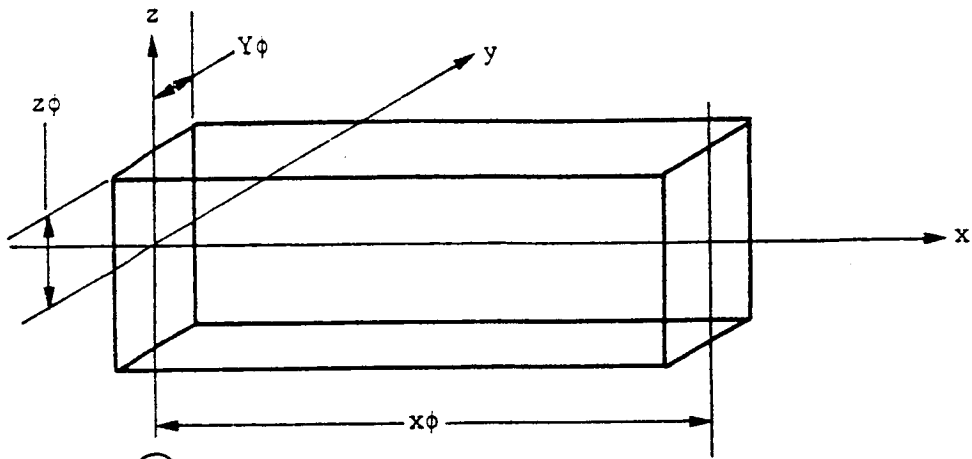
X0 = Length of figure

Y0 = Width of figure

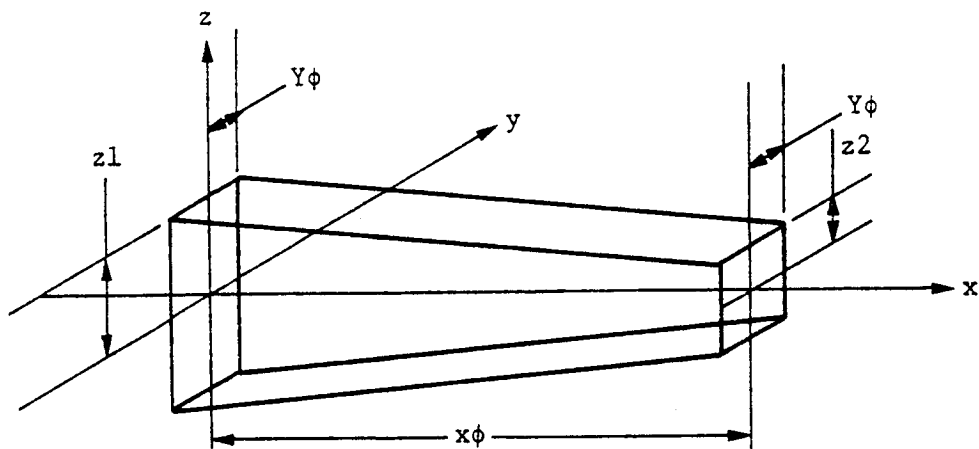
Z0 = Base of rectangular figure

Z1 = First base of sym. or nonsym. trapezoid

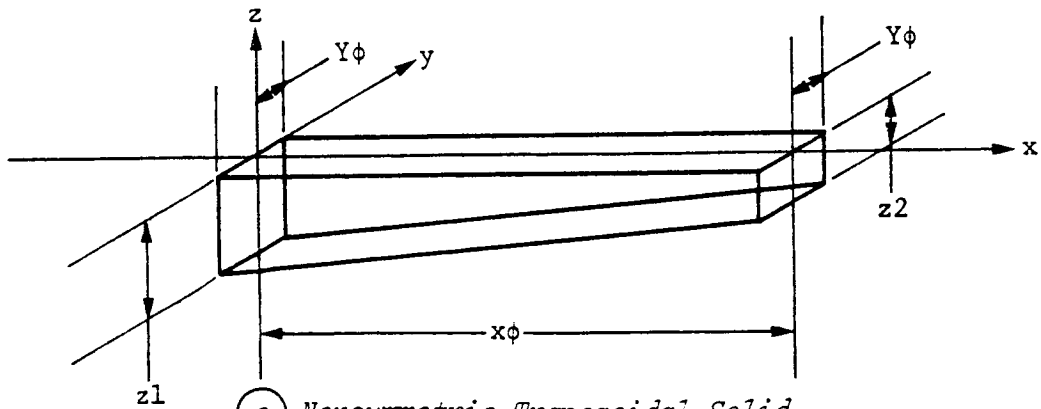
Z2 = Second base of sym. or nonsym. trapezoid



(a) Rectangular Solid



(b) Symmetric Trapezoidal Solid



(c) Nonsymmetric Trapezoidal Solid

Figure A-19. - Rectangular and trapezoidal shape coordinate system.

C) Triangular beam-shaped entities. - A triangular cross-sectional beam may be created during the detailed graphic representation generation for the environment, manipulator or load objects.

If the requested component is a triangular beam structure all of the required input values are given by:

ENTER TRIANGLE SIDE LENGTH, IN [length units]

ENTER SEGMENT LENGTH, IN [length units]

ENTER NUMBER OF SEGMENTS

The length inputs should be the value equivalences in I/O units, meters or inches. The user prompt for length of the base is also used as the triangular height. The length of the segments of the triangular beam structure combined with the number of segments to be included and the inscribed triangle parameters allow the definition of the entity data points. The beam length is measured along the x-axis from $x=0$ to $x=\text{the input number of segments multiplied by an individual segment length (NSEG*SEGL)}$. The data points defining the beam are computed in a shape coordinate system and stored in an array as Cartesian coordinates. Figure A-20 illustrates a triangular cross-sectional beam entity and uses the symbolism:

TRIL = Triangle side length

SEGL = Segment length

NSEG = Number of segments

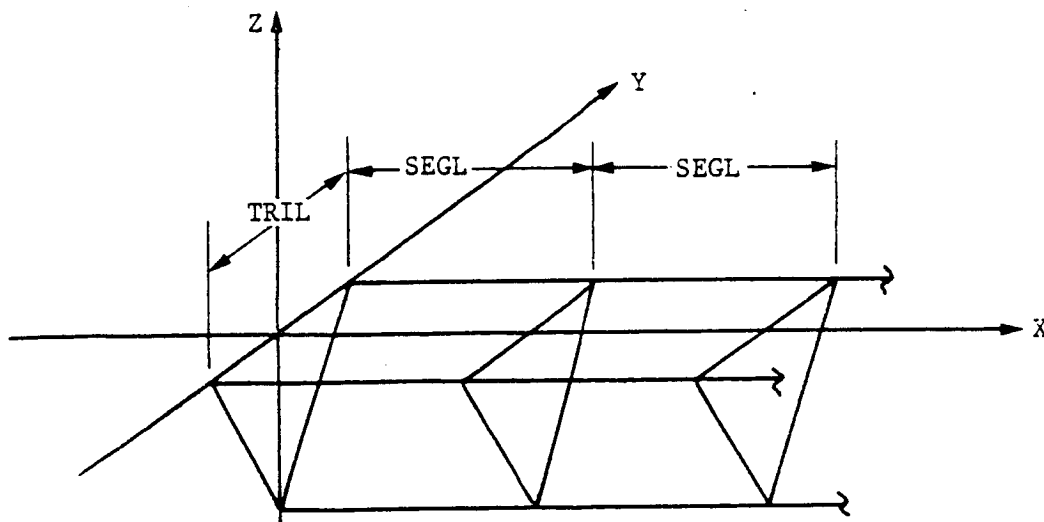


Figure A-20. - Triangular cross-section beam coordinate system.

D) Data tablet-defined structures. - The routine that interfaces with a data tablet device is called within the system definition function during detailed graphic representation generation for the environment, the robotic arm or load if input of planar x/y values are needed. The points are entered via the Data Tablet device with a touch-sensing pen.

The user is asked:

ENTER NUMBER OF POINTS TO BE INPUT
MAXIMUM OF 25
DO NOT INCLUDE REPEAT OF FIRST POINT
PROGRAM AUTOMATICALLY CONNECTS LAST
POINT BACK TO FIRST POINT

ENTER 3 POINTS USING DATA TABLET

At which time the data points should be input at the data tablet.

The points are displayed by the graphics as they are input by the user. The discretized x and y values of the points that are perceived by the external device will be echoed at the user terminal. The user-entered integers and the equivalent scaled values used for the data are scrolled on the screen, for example, as the observed sequence

1	1368	727	7973	-11096
2	1260	831	4760	-8002
3	1215	614	3421	-14458

where the fourth and fifth columns are the input integer x,y values (columns 2 and 3) times the internal scale factor.

When finished with all the point data the program quests a termination flag for the entry process with:

ENTER 1 TO TERMINATE

The continuing prompts for this option deal with the values needed to further scale the data tablet figure using knowledge about the actual dimensions of the object being modelled. The user is asked to input two points between which there is a known dimension. The distance between the two virtual points, saved as discrete integers in the program, is entered and the program calculates the real number data point values of the figure perimeters. The interaction follows as:

ENTER TWO POINTS USING DATA TABLET
BETWEEN WHICH THERE IS A KNOWN DISTANCE,
FOR SCALING

(These should be specified via the data tablet device.)

Then the user inputs:

ENTER DIMENSION BETWEEN TWO POINTS IN [length units]

The origin to be used for the figure's coordinate reference frame is correlated to:

SPECIFY POINT FOR ORIGIN USING DATA TABLET
FIGURE WILL BE TRANSLATED TO THIS POSITION.

After which the inquiry for the depth to be used for the object is required. The depth will be applied uniformly along the whole entity. Specify:

ENTER Z (DEPTH IS +/-Z) IN [length units]

The data tablet points commonly define a shape that cannot be described with the primitive shapes already incorporated. The (x,y) points are reckoned in the screen coordinate system. The x-axis is to the right on the Evans and Sutherland screen, y-axis is up, and the z-axis is out of the screen. The data points are loaded into the component array as Cartesian coordinates in this shape reference system. Figure A-21 illustrates the coordinate axes system for a data tablet structure with:

Z = Depth of object

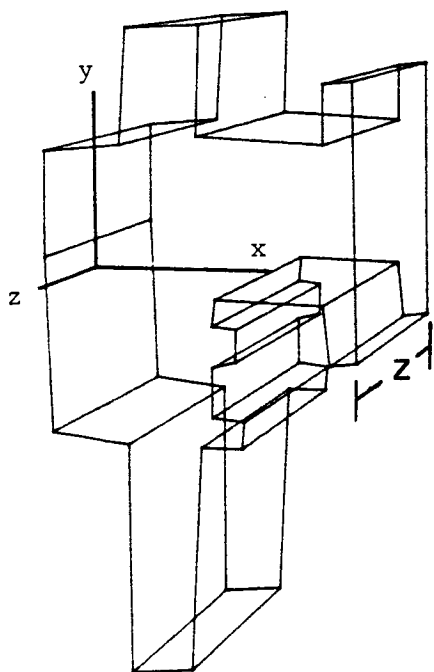


Figure A-21. - Data Tablet component coordinate system.

E) Fillet entities. - The definition of concave or convex fillets is also allowed during detailed graphic representation generation for the environment, the robotic arm or load.

Entries are:

ENTER FILLET RADIUS IN [length units]

and

ENTER LENGTH IN [length units]

For shape radius and length, the data defining the shape are computed in a shape coordinate system. The x-axis is along the shape centerline and the shape length is measured from $x=0$ to $x=\text{the input fillet length}$. The data points are loaded into an array as Cartesian coordinates in the shape coordinate system. Figure A-22 shows a fillet with the following dimensions:

RADIUS = Radius of fillet
CLEN = Length of fillet

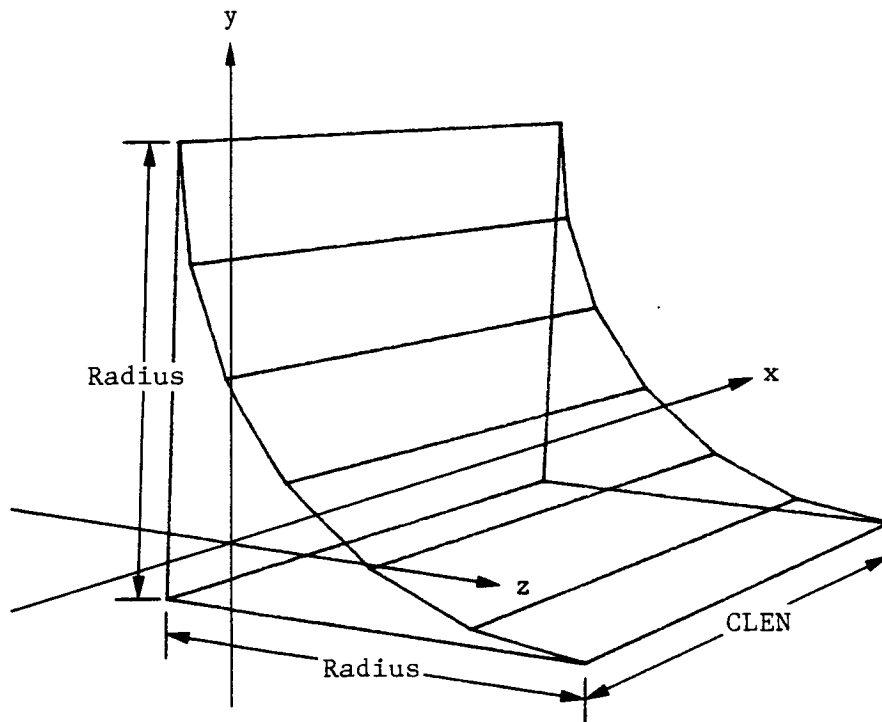


Figure A-22. - Fillet component coordinate system.

F) Nonplanar entities. - During the detailed graphics representation generation for an environment, arm or load the user may define a three-dimensional nonplanar entity by specification of a set of (x,y,z) coordinates. Note that the data tablet option only provides a means of specifying (x,y) coordinate pairs. The nonplanar entry process is especially applicable for the development of obstacles in a ROBSIM environment that are useful for simulation tests of manipulator arm path trajectory avoidance techniques.

The user is allowed several modes of data input. One method requires interactive input of the point values, and the other mode reads a presaved ('.OBS') file of (x,y,z) coordinate sets to replace user input of the component data. An example predefined obstacle file may appear as:

```
16
-0.5 1.0 0.5
0.5 1.0 0.5
0.5 -1.0 0.5
-0.5 -1.0 0.5
-0.5 1.0 0.5
-0.5 1.0 -0.5
0.5 1.0 -0.5
0.5 1.0 0.5
0.5 1.0 -0.5
0.5 -1.0 -0.5
0.5 -1.0 0.5
0.5 -1.0 -0.5
-0.5 -1.0 -0.5
-0.5 -1.0 0.5
-0.5 -1.0 -0.5
-0.5 1.0 -0.5    [a rectangular solid centered about (0,0,0)]
```

The first record is the number of connected vertices or points to define this entity (i.e., the number of points in the file). The other records include the sequence of (x,y,z) values for every point to be connected sequentially in the object perimeter.

To specify the mode of data input during nonplanar entity creation:

```
DO YOU WISH TO READ A COMPONENT DATA FILE?
  ENTER 1 TO READ A FILE
  ENTER 2 TO INPUT COMPONENT FROM TERMINAL
```

If reading a predescribed file the user is then asked:

```
ENTER THE COMPONENT DATA FILE NAME:
  EXAMPLE - ROBDEVICE:[ROBDIR]PLANNER.OBS
```

Else, if interactively setting the obstacle data points, the number of obstacle or nonplanar entity points to be input along with the x,y,z values ascribing the object perimeter are questioned:

ENTER NUMBER OF POINTS TO BE INPUT
MAXIMUM OF 25
DO NOT INCLUDE REPEAT OF FIRST POINT
PROGRAM AUTOMATICALLY CONNECTS LAST
POINT BACK TO FIRST POINT

ENTER X,Y,Z VALUES IN [length units] FOR
POINT 1: (input value)
POINT 2: (input value)

(etc)

For both modes, the scaling of the data entered is accompanied by:

ENTER A SCALING FACTOR FOR THESE VALUES:

The points for the shape are input in the screen coordinates. The x-axis is to the right on the screen, y-axis is up, and z-axis is out of the screen. The data points are loaded into an array as Cartesian coordinates in the shape coordinate system. A maximum number of points are allowed as input for this option.

The points are displayed in the graphics as they are specified by the user. Figure A-23 is an example of a nonplanar, or obstacle, entity.

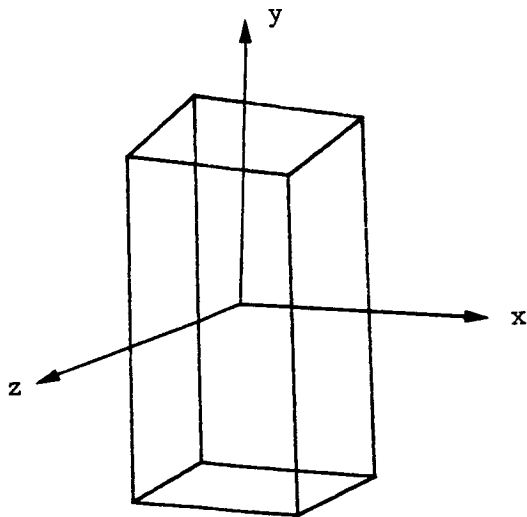


Figure A-23. - Nonplanar, obstacle component coordinate system.

Procedure for Creating a System Workcell Environment

The user has the capability to specify a robotic simulation environment with a detailed physical representation that may later be included in a total system file. The environment components are defined similar to the detailed arm construction, by combinations of basic geometric shapes (cylinders, cones, rectangular solids, symmetric or nonsymmetric trapezoidal figures, triangular cross-sectional beams, fillet components, data tablet-defined entities and obstacles, also used for nonplanar structures).

Subroutines are provided to calculate the data points for each requested shape. Additional subroutines are called to position and orient the components relative to the world coordinate system, draw the component with the graphics package, while allowing the user the freedom to change the graphics display perspective with the E&S control dials and add the data to the database describing the environment.

The interactive prompts again include the I/O type units to be used. Conversions are made to the program internal metric units for calculations.

For initializing the display, if the graphics is on, the user should input the span for the environment to be used in scaling the graphics:

INPUT SPAN OF ENVIRONMENT SETTING IN [length units]
FOR SCALING GRAPHICS

The shape select flag allowing the user to pick the geometric shapes with which to build up detailed representations of the environment is next required. The interaction that transpires for any of these entities is as described earlier under Procedure for creating a detailed robot arm geometry. Answer:

SELECT SHAPE
1 = CYLINDER
2 = CONE
3 = RECTANGULAR SOLID
4 = SYM TRAPEZOID
5 = NONSYM TRAPEZOID
6 = TRIANGULAR STRUCTURE
7 = DATA TABLET STRUCTURE
8 = FILLET
9 = OBSTACLE ENTITY
ENTER INTEGER CHOICE

The user, or simulated camera, view of the displayed components may be altered with the E&S analog control dials during the environment definition.

After answering all of the component properties prompts, enter:

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

When satisfied with the current component, evaluate the need for a more detailed definition. If the environment depiction is not complete, define another component by entering a 1 to the next prompt; otherwise, a response of 2 will allow the termination of the environment setup portion of the system definition function and will write the data to file. Enter the request to:

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO SAVE FILE AND EXIT

When finished with environment specification, if the graphics is in effect the next message appears as:

ENTER RETURN TO TERMINATE GRAPHICS AND CONTINUE

After acceptance of the resulting environment built, an unformatted environment data ('.ENV') file will be written; the contents of the file are the pertinent COMMON blocks defining an environment for a robotic system. The user is prompted for the file name under which the file is to be stored:

ENTER FILENAME OF ENVIRONMENT FILE
TO BE CREATED. FILE MUST NOT CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANDET.ENV

Sample run. - A sample of an environment building scheme follows in Example A-5. Figures A-24 through A-26 were generated as a result of the interactive session employing the graphics option.

Example A-5

ROBOTIC SYSTEM SIMULATION PROGRAM (ROBSIM)

ENTERING SYSTEM DEFINITION FUNCTION

DEFAULT LOGICAL UNIT ASSIGNMENTS USED WITHIN ROBSIM

LU	USE
5	READ UNIT (TERMINAL)
6	WRITE UNIT (TERMINAL)
7	PRINTED OUTPUT UNIT
8-9	SIMULATION INPUT FILE
10	SIMULATION OUTPUT FILE
11	ACTUATOR PARAMETERS INPUT FILE
14	LOAD OBJECTS DATA FILE
15	ERROR MESSAGE FILE
16	GAIN CONSTANTS FILE
17	TORQUE DATA INPUT FILE
18	ACC-VEL-THETA FILE
19	PROGRAMS OPTIONS FILE
20	PLOT DATA FILE
21	MOTION TIME HISTORY FILE
22	HARDWARE CONTROL SIGNALS
23	CONTROL OPTIONS INPUT FILE
24	CONTROL MODULE OUTPUT FILE

USER WILL BE PROMPTED FOR FILENAMES
TO ASSOCIATE WITH EACH LOGICAL UNIT
WHEN REQUIRED

ENTER RETURN TO CONTINUE

<CR>

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE/MODIFY ARM DATA FILE
2	CREATE/MODIFY DETAILED ENVIRONMENT
3	CREATE/MODIFY LOAD OBJECTS FILE
4	CREATE SYSTEM DATA FILE
5	TERMINATE SYSTEM DEFINITION EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

2

WHICH UNITS DO YOU WISH TO USE FOR I/O?

ENTER 1 FOR METRIC UNITS

ENTER 2 FOR ENGLISH UNITS

1

UNITS FOR INPUT/OUTPUT ARE AS FOLLOWS:

LENGTH	METERS
VELOCITY	METERS/SEC
ACCELERATION	METERS/S**2
MASS	KILOGRAMS
INERTIA	KG-M**2
FORCE	NEWTONS
TORQUE	N-M

INPUT SPAN OF ENVIRONMENT SETTING IN METERS
FOR SCALING GRAPHICS

1.5

SELECT SHAPE

1 = CYLINDER
2 = CONE
3 = RECTANGULAR SOLID
4 = SYM TRAPEZOID
5 = NONSYM TRAPEZOID
6 = TRIANGULAR STRUCTURE
7 = DATA TABLET STRUCTURE
8 = FILLET
9 = OBSTACLE ENTITY

ENTER INTEGER CHOICE

3

ENTER LENGTH (X) IN METERS

1.

ENTER Y (WIDTH IS +/-Y) IN METERS

0.05

ENTER Z (BASE IS +/-Z) IN METERS

0.5

ENTER 1 IF ROTATIONS REQUIRED

ENTER 2 IF TRANSLATION ONLY

2

ENTER X,Y,Z TRANSLATION IN METERS

0.,0.,0.

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***

ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

2

```

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO SAVE FILE AND EXIT
1

SELECT SHAPE
  1 = CYLINDER
  2 = CONE
  3 = RECTANGULAR SOLID
  4 = SYM TRAPEZOID
  5 = NONSYM TRAPEZOID
  6 = TRIANGULAR STRUCTURE
  7 = DATA TABLET STRUCTURE
  8 = FILLET
  9 = OBSTACLE ENTITY
ENTER INTEGER CHOICE
3

ENTER LENGTH (X) IN METERS
0.65

ENTER Y (WIDTH IS +/-Y) IN METERS
0.025

ENTER Z (BASE IS +/-Z) IN METERS
0.025

ENTER 1 IF ROTATIONS REQUIRED
ENTER 2 IF TRANSLATION ONLY
1

ENTER AXIS OF ROTATION
  1 = X-AXIS
  2 = Y-AXIS
  3 = Z-AXIS
3

ENTER ROTATION ANGLE, IN DEGREES
-90.

ENTER 1 TO SPECIFY ANOTHER ROTATION
ENTER 2 TO TERMINATE ROTATION INPUT
2

ENTER X,Y,Z TRANSLATION IN METERS
0.025,-0.05,0.475

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED          ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

```

*** HARD COPY ***

ENTER ".PIC" FILE NAME PREFIX

(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT

ENTER 2 IF COMPONENT IS CORRECT

2

ENTER 1 TO DEFINE ANOTHER COMPONENT

ENTER 2 TO SAVE FILE AND EXIT

1

SELECT SHAPE

1 = CYLINDER

2 = CONE

3 = RECTANGULAR SOLID

4 = SYM TRAPEZOID

5 = NONSYM TRAPEZOID

6 = TRIANGULAR STRUCTURE

7 = DATA TABLET STRUCTURE

8 = FILLET

9 = OBSTACLE ENTITY

ENTER INTEGER CHOICE

3

ENTER LENGTH (X) IN METERS

0.65

ENTER Y (WIDTH IS +/-Y) IN METERS

0.025

ENTER Z (BASE IS +/-Z) IN METERS

0.025

ENTER 1 IF ROTATIONS REQUIRED

ENTER 2 IF TRANSLATION ONLY

1

ENTER AXIS OF ROTATION

1 = X-AXIS

2 = Y-AXIS

3 = Z-AXIS

3

ENTER ROTATION ANGLE, IN DEGREES

-90.

ENTER 1 TO SPECIFY ANOTHER ROTATION

ENTER 2 TO TERMINATE ROTATION INPUT

2

ENTER X,Y,Z TRANSLATION IN METERS

0.975,-0.05,0.475

A-90

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

2

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO SAVE FILE AND EXIT

1

SELECT SHAPE

- 1 = CYLINDER
- 2 = CONE
- 3 = RECTANGULAR SOLID
- 4 = SYM TRAPEZOID
- 5 = NONSYM TRAPEZOID
- 6 = TRIANGULAR STRUCTURE
- 7 = DATA TABLET STRUCTURE
- 8 = FILLET
- 9 = OBSTACLE ENTITY

ENTER INTEGER CHOICE

3

ENTER LENGTH (X) IN METERS

0.65

ENTER Y (WIDTH IS +/-Y) IN METERS

0.025

ENTER Z (BASE IS +/-Z) IN METERS

0.025

ENTER 1 IF ROTATIONS REQUIRED

ENTER 2 IF TRANSLATION ONLY

1

ENTER AXIS OF ROTATION

- 1 = X-AXIS
- 2 = Y-AXIS
- 3 = Z-AXIS

3

ENTER ROTATION ANGLE, IN DEGREES

-90.

ENTER 1 TO SPECIFY ANOTHER ROTATION

ENTER 2 TO TERMINATE ROTATION INPUT

2

End

ENTER X,Y,Z TRANSLATION IN METERS
0.975,-0.05,-0.475

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

2

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO SAVE FILE AND EXIT

1

SELECT SHAPE

- 1 = CYLINDER
- 2 = CONE
- 3 = RECTANGULAR SOLID
- 4 = SYM TRAPEZOID
- 5 = NONSYM TRAPEZOID
- 6 = TRIANGULAR STRUCTURE
- 7 = DATA TABLET STRUCTURE
- 8 = FILLET
- 9 = OBSTACLE ENTITY

ENTER INTEGER CHOICE

3

ENTER LENGTH (X) IN METERS
0.65

ENTER Y (WIDTH IS +/-Y) IN METERS
0.025

ENTER Z (BASE IS +/-Z) IN METERS
0.025

ENTER 1 IF ROTATIONS REQUIRED
ENTER 2 IF TRANSLATION ONLY

1

ENTER AXIS OF ROTATION

- 1 = X-AXIS
- 2 = Y-AXIS
- 3 = Z-AXIS

3

ENTER ROTATION ANGLE, IN DEGREES
-90.
A-92

ENTER 1 TO SPECIFY ANOTHER ROTATION
ENTER 2 TO TERMINATE ROTATION INPUT

2

ENTER X,Y,Z TRANSLATION IN METERS
0.025,-0.05,-0.475

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

2

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO SAVE FILE AND EXIT

1

SELECT SHAPE
1 = CYLINDER
2 = CONE
3 = RECTANGULAR SOLID
4 = SYM TRAPEZOID
5 = NONSYM TRAPEZOID
6 = TRIANGULAR STRUCTURE
7 = DATA TABLET STRUCTURE
8 = FILLET
9 = OBSTACLE ENTITY
ENTER INTEGER CHOICE

1

ENTER DIAMETER IN METERS
0.3

ENTER LENGTH IN METERS
0.05

ENTER 1 IF ROTATIONS REQUIRED
ENTER 2 IF TRANSLATION ONLY

1

ENTER AXIS OF ROTATION
1 = X-AXIS
2 = Y-AXIS
3 = Z-AXIS

3

ENTER ROTATION ANGLE, IN DEGREES
-90.

ENTER 1 TO SPECIFY ANOTHER ROTATION
ENTER 2 TO TERMINATE ROTATION INPUT
2

ENTER X,Y,Z TRANSLATION IN METERS
-0.2,-0.15,0.

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT
2

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO SAVE FILE AND EXIT
1

SELECT SHAPE
1 = CYLINDER
2 = CONE
3 = RECTANGULAR SOLID
4 = SYM TRAPEZOID
5 = NONSYM TRAPEZOID
6 = TRIANGULAR STRUCTURE
7 = DATA TABLET STRUCTURE
8 = FILLET
9 = OBSTACLE ENTITY
ENTER INTEGER CHOICE

2

ENTER DIAMETER IN METERS
0.33

ENTER TOP DIAMETER OF CONE IN METERS
0.25

ENTER LENGTH IN METERS
0.5

ENTER 1 IF ROTATIONS REQUIRED
ENTER 2 IF TRANSLATION ONLY
1

ENTER AXIS OF ROTATION

1 = X-AXIS

2 = Y-AXIS

3 = Z-AXIS

3

ENTER ROTATION ANGLE, IN DEGREES

90.

ENTER 1 TO SPECIFY ANOTHER ROTATION

ENTER 2 TO TERMINATE ROTATION INPUT

2

ENTER X,Y,Z TRANSLATION IN METERS

-0.2,-0.7,0.

*** E&S DIALS CONTROL OF GRAPHICS ***

*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***

ENTER ".PIC" FILE NAME PREFIX

(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT

ENTER 2 IF COMPONENT IS CORRECT

2

ENTER 1 TO DEFINE ANOTHER COMPONENT

ENTER 2 TO SAVE FILE AND EXIT

2

ENTER RETURN TO TERMINATE GRAPHICS AND CONTINUE

<CR>

ENTER FILENAME OF ENVIRONMENT FILE

TO BE CREATED. FILE MUST NOT CURRENTLY EXIST.

THE TOTAL NUMBER OF CHARACTERS IN FILENAME

CAN NOT EXCEED 40

EXAMPLE - ROBDEVICE:[ROBDIR]PLANDET.ENV

PLANAR.ENV

ENVIRONMENT DATA FILE HAS BEEN WRITTEN

ALL COMMON BLOCKS ARE SAVED

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE/MODIFY ARM DATA FILE
2	CREATE/MODIFY DETAILED ENVIRONMENT
3	CREATE/MODIFY LOAD OBJECTS FILE
4	CREATE SYSTEM DATA FILE
5	TERMINATE SYSTEM DEFINITION EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

5

EXITING FROM SYSTEM DEFINITION FUNCTION

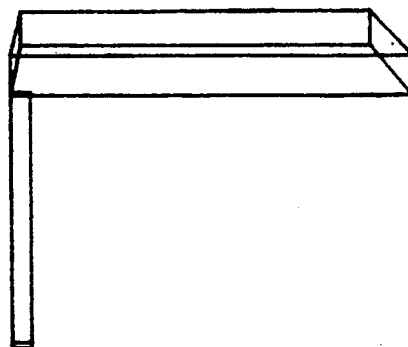


Figure A-24. - First two detailed environment components.

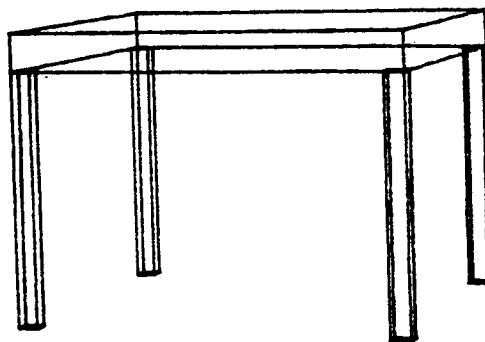


Figure A-25. - Completion of one entity in detailed environment.

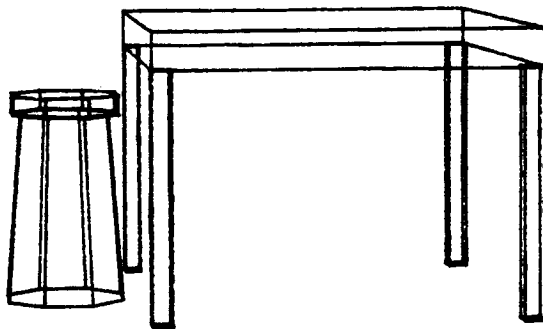


Figure A-26. - Complete detailed environment.

Procedure for Creating a Load Objects File

Through this ROBSIM option, the user has the capability to specify a detailed physical representation for the robotic load objects to be used. Similar to the detailed arm and environment constructions, the load object's components are defined as rotations and translations of combinations of basic geometric shapes (cylinders, cones, rectangular solids, symmetric or nonsymmetric trapezoidal figures, triangular cross-sectional beams, fillet components, data tablet-defined entities, and nonplanar structures, also used for obstacles). This procedure creates a new file, or modifies an existing file of load objects, and includes the capability to specify the detailed geometry at the first user creation session for the load objects.

The load definition process first calls upon the user to define whether the load data are from an existing file or if they will be input from the terminal. If the load already exists, it is read from the saved file. A series of questions apply for the input of new data or modification of existing data. Additional information is required to position and orient the components relative to the load coordinate system. The component will be drawn with the graphics package while allowing the user the freedom to change the graphics display perspective with the E&S control dials, and the data will be added to the database describing the load objects. After the data have been modified or created, a user-specified file is opened and the data saved.

The interactive inputs are in order:

```
DO YOU WISH TO CREATE LOAD OBJECT DATA
OR MODIFY AND/OR USE EXISTING DATA?
  ENTER 0 TO CREATE NEW DATA
  ENTER 1 TO READ IN EXISTING DATA
```

If initial creation, first the user specifies the type of input/output units to be used, and then the question relates to the number of loads desired in the load object file. The construction questions will repeat for each load entered at the prompt:

```
ENTER THE NUMBER OF LOAD OBJECTS YOU WISH
TO DEFINE--MAX ALLOWABLE IS 10
```

There is a constraint placed on the number of load objects allowed in any one file.

Else if one is reading existing data, the file containing this previously created data is opened as given by:

ENTER THE NAME OF THE FILE CONTAINING LOAD DATA
THE TOTAL NUMBER OF CHARACTERS IN THE FILENAME
CANNOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANDET.LOD

The user is asked whether he wishes the option to list the load characteristics as they are currently saved before modifications begin. The information that will be scrolled to the terminal includes the type I/O units opted by the user for load definition, the load coordinate system origin location and orientation matrix and the values of load length, radius, center of gravity location, mass, inertia matrix elements and point mass parameters. The RETURN key should be depressed after such a list is written to the user's terminal. While incrementing through each load, the prompts appear as:

ENTER
1 TO LIST AND/OR MODIFY CURRENT DATA
2 TO CONTINUE PROGRAM EXECUTION

If the decision is to modify the load after entering a 1 above, then the following input is a 1 to the question:

DO YOU WISH TO
1 MODIFY CURRENT LOAD DATA
2 CONTINUE

At this time one begins to define the load properties during both the modification or creation modes. The same procedure of calls applies for changes to the load origin location and local coordinate system orientation, load length, radius, mass, cg location, inertia matrix, point mass values and point mass locations as occur during initial input. If in modification mode, the user should run the process after choosing from the following categories:

LOAD J DATA MODIFICATIONS
SELECT CATEGORY OF DATA TO BE MODIFIED

CAT	DEFINITION
1	LOAD LOCATION AND ORIENTATION
2	LOAD LENGTH AND RADIUS
3	LOAD CENTER OF MASS
4	LOAD MASS
5	LOAD INERTIA MATRIX
6	POINT MASS VALUES AND LOCATIONS
7	TERMINATE LOAD MODIFICATION

ENTER INTEGER MODIFICATION CATEGORY DESIRED

The inquiries to the user then include:

DEFINITION OF LOAD J

ENTER THE WORLD X, Y, Z COORDINATES DEFINING
THE ORIGIN OF THE LOAD LOCAL COORDINATE SYSTEM
THESE DISTANCES SHOULD BE INPUT IN [length units]

and

SPECIFY ROTATION SEQUENCE FOR ORIENTATION
OF LOAD COORDINATE SYSTEM WITH RESPECT TO
THE WORLD COORDINATE SYSTEM

THE SEQUENCE IS SPECIFIED BY A SERIES OF
ROTATION AXIS/ROTATION ANGLE PAIRS WHERE

1 REPRESENTS THE X AXIS

2 REPRESENTS THE Y AXIS

3 REPRESENTS THE Z AXIS

A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION

ENTER 1ST ROTATION ANGLE (DEG)

ENTER 1 TO SPECIFY ANOTHER AXIS/ANGLE PAIR

ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT

The geometry properties for the current load are then input:

SPECIFY LENGTH OF LOAD J IN [length units]
THE FIRST END IS AT THE LOAD COORDINATE SYSTEM
ORIGIN. CENTERLINE OF LOAD IS ALONG X AXIS
SO THE LENGTH WILL DEFINE THE SECOND END

and

SPECIFY RADIUS OF LOAD J IN [length units]
FOR USE IN INERTIA CALCULATIONS

The user selection for mode of cg calculation:

ENTER 1 TO HAVE PROGRAM COMPUTE CENTER OF MASS
ENTER 2 TO REQUEST USER INPUT OF CENTER OF MASS

If placing the cg at a particular location:

SPECIFY CENTER OF MASS LOCATION FOR LOAD J
IN ITS OWN LOCAL COORDINATE SYSTEM

ENTER X COORDINATE OF CENTER OF MASS IN [length units]

ENTER Y COORDINATE OF CENTER OF MASS IN [length units]

ENTER Z COORDINATE OF CENTER OF MASS IN [length units]

The mass of the load is specified with:

SPECIFY MASS OF LOAD J IN [mass units]

The user choice for mode of load inertia definition:

SPECIFY INERTIA MATRIX FOR LOAD J

ENTER 1 TO HAVE PROGRAM COMPUTE INERTIA MATRIX
ENTER 2 TO REQUEST USER INPUT OF INERTIA MATRIX

If requesting a special inertia matrix weighting:

ENTER 1ST COLUMN OF INERTIA MATRIX
INPUT 3 REAL NUMBERS SEPARATED BY COMMAS
INERTIA DATA SHOULD HAVE UNITS OF [inertia units]

ENTER 2ND COLUMN OF INERTIA MATRIX
INPUT 3 REAL NUMBERS SEPARATED BY COMMAS
INERTIA DATA SHOULD HAVE UNITS OF [inertia units]

ENTER 3RD COLUMN OF INERTIA MATRIX
INPUT 3 REAL NUMBERS SEPARATED BY COMMAS
INERTIA DATA SHOULD HAVE UNITS OF [inertia units]

Again, in the load definition operation, specify:

ENTER 1 TO SPECIFY POINT MASSES FOR LOAD J
ENTER 2 NOT TO SPECIFY POINT MASSES FOR LOAD J

If adding point masses for a more accurate arrangement,
input these in the load local coordinate system with:

SPECIFY MASS OF POINT MASS FOR LOAD J IN [mass units]

and

ENTER X,Y,Z LOCATION OF POINT MASS J IN [length units]
IN LOAD J COORDINATE SYSTEM

ENTER 3 REAL NUMBERS

and the continuation flag for point mass input:

ENTER 1 TO CONTINUE POINT MASS INPUT
ENTER 2 TO TERMINATE POINT MASS INPUT

The current state of the load object most recently defined is printed to the terminal upon finishing the definition process. The program further inquires if redefinition of this load's properties is desired. After final completion of the location, orientation and mass properties, a detailed graphics session begins.

For option to build a more intricate load objects file when in modification mode for the load file, the user is asked:

DO YOU WISH TO

- 1 MODIFY GRAPHICS REPRESENTATION FOR LOAD J
- 2 CONTINUE

A 2 for this question continues the basic geometry modification prompts for successive loads, but does not allow user definition of detailed geometry components. On the other hand, a response of 1 cues the following graphics conversation that occurs automatically during the initial creation phase:

INPUT SPAN OF LOAD OBJECT SETTING IN [length units]
FOR SCALING GRAPHICS

The detailed geometry primitive inputs are required of the user by:

SELECT SHAPE

- 1 = CYLINDER
- 2 = CONE
- 3 = RECTANGULAR SOLID
- 4 = SYM TRAPEZOID
- 5 = NONSYM TRAPEZOID
- 6 = TRIANGULAR STRUCTURE
- 7 = DATA TABLET STRUCTURE
- 8 = FILLET
- 9 = NONPLANAR ENTITY

ENTER INTEGER CHOICE

The translation and orientation to be applied to this component will be interjected as previously described for sketching detailed components. The corresponding geometric entity building routine will be called. The steps for input during all of these unique routines were charted in subsections A) through F) under the above heading Procedure for creating a detailed robot arm geometry.

After each geometric component primitive has been created, return:

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

Upon completion of a component entry:

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO SAVE FILE AND EXIT

Enter a 1 if the load object definition is not complete and another component is desired to be included in this single load object. With a 2 input, the load description is considered complete, the graphics terminated and the file saved. The contents of the file are the pertinent COMMON blocks defining the mass properties and graphics of the loads for a future system. The graphics remains on the Evans and Sutherland screen until a RETURN is given:

ENTER RETURN TO TERMINATE GRAPHICS AND CONTINUE

The user is prompted for the file name ('.LOD') under which the file is to be stored:

ENTER NAME OF FILE TO SAVE LOAD DATA IN
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CANNOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANNER.LOD
PLANAR.LOD

Sample run. - An example, A-6, of an interactive definition procedure for a load objects file follows. This particular file contains two load objects; the first has one detailed component; the second specifies two included components (Fig. A-27 and A-28).

Example A-6

ROBOTIC SYSTEM SIMULATION PROGRAM (ROBSIM)

ENTERING SYSTEM DEFINITION FUNCTION

DEFAULT LOGICAL UNIT ASSIGNMENTS USED WITHIN ROBSIM

LU	USE
5	READ UNIT (TERMINAL)
6	WRITE UNIT (TERMINAL)
7	PRINTED OUTPUT UNIT
8-9	SIMULATION INPUT FILE
10	SIMULATION OUTPUT FILE
11	ACTUATOR PARAMETERS INPUT FILE
14	LOAD OBJECTS DATA FILE
15	ERROR MESSAGE FILE
16	GAIN CONSTANTS FILE
17	TORQUE DATA INPUT FILE
18	ACC-VEL-THETA FILE
19	PROGRAMS OPTIONS FILE
20	PLOT DATA FILE
21	MOTION TIME HISTORY FILE
22	HARDWARE CONTROL SIGNALS
23	CONTROL OPTIONS INPUT FILE
24	CONTROL MODULE OUTPUT FILE

USER WILL BE PROMPTED FOR FILENAMES
TO ASSOCIATE WITH EACH LOGICAL UNIT
WHEN REQUIRED

ENTER RETURN TO CONTINUE

<CR>

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE/MODIFY ARM DATA FILE
2	CREATE/MODIFY DETAILED ENVIRONMENT
3	CREATE/MODIFY LOAD OBJECTS FILE
4	CREATE SYSTEM DATA FILE
5	TERMINATE SYSTEM DEFINITION EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

3

DO YOU WISH TO CREATE LOAD OBJECT DATA
OR MODIFY AND/OR USE EXISTING DATA?

ENTER 0 TO CREATE NEW DATA

ENTER 1 TO READ IN EXISTING DATA

0

WHICH UNITS DO YOU WISH TO USE FOR I/O?
ENTER 1 FOR METRIC UNITS
ENTER 2 FOR ENGLISH UNITS

1

UNITS FOR INPUT/OUTPUT ARE AS FOLLOWS:

LENGTH	METERS
VELOCITY	METERS/SEC
ACCELERATION	METERS/S**2
MASS	KILOGRAMS
INERTIA	KG-M**2
FORCE	NEWTONS
TORQUE	N-M

ENTER THE NUMBER OF LOAD OBJECTS YOU WISH
TO DEFINE--MAX ALLOWABLE IS 10

2

DEFINITION OF LOAD 1

ENTER THE WORLD X, Y, Z COORDINATES DEFINING
THE ORIGIN OF THE LOAD LOCAL COORDINATE SYSTEM
THESE DISTANCES SHOULD BE INPUT IN METERS
0.,0.,0.

SPECIFY ROTATION SEQUENCE FOR ORIENTATION
OF LOAD COORDINATE SYSTEM WITH RESPECT TO
THE WORLD COORDINATE SYSTEM
THE SEQUENCE IS SPECIFIED BY A SERIES OF
ROTATION AXIS/ROTATION ANGLE PAIRS WHERE

- 1 REPRESENTS THE X AXIS
- 2 REPRESENTS THE Y AXIS
- 3 REPRESENTS THE Z AXIS

A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION

1

ENTER 1ST ROTATION ANGLE (DEG)

0.

ENTER 1 TO SPECIFY ANOTHER AXIS/ANGLE PAIR
ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT

2

SPECIFY LENGTH OF LOAD 1 IN METERS
THE FIRST END IS AT THE LOAD COORDINATE SYSTEM
ORIGIN. CENTERLINE OF LOAD IS ALONG X AXIS
SO THE LENGTH WILL DEFINE THE SECOND END

0.04

SPECIFY RADIUS OF LOAD 1 IN METERS
FOR USE IN INERTIA CALCULATIONS

0.01

SPECIFY CENTER OF MASS LOCATION FOR LOAD 1
IN ITS OWN LOCAL COORDINATE SYSTEM

ENTER 1 TO HAVE PROGRAM COMPUTE CENTER OF MASS
ENTER 2 TO REQUEST USER INPUT OF CENTER OF MASS

1

SPECIFY MASS OF LOAD 1 IN KILOGRAMS

2.

SPECIFY INERTIA MATRIX FOR LOAD 1

ENTER 1 TO HAVE PROGRAM COMPUTE INERTIA MATRIX
ENTER 2 TO REQUEST USER INPUT OF INERTIA MATRIX

1

ENTER 1 TO SPECIFY POINT MASSES FOR LOAD 1
ENTER 2 NOT TO SPECIFY POINT MASSES FOR LOAD 1

2

INPUT SPAN OF LOAD OBJECT SETTING IN METERS
FOR SCALING GRAPHICS

1.5

SELECT SHAPE

- 1 = CYLINDER
- 2 = CONE
- 3 = RECTANGULAR SOLID
- 4 = SYM TRAPEZOID
- 5 = NONSYM TRAPEZOID
- 6 = TRIANGULAR STRUCTURE
- 7 = DATA TABLET STRUCTURE
- 8 = FILLET
- 9 = NONPLANAR ENTITY

ENTER INTEGER CHOICE

6

ENTER TRIANGLE SIDE LENGTH, IN METERS

0.02

ENTER SEGMENT LENGTH, IN METERS

0.02

ENTER NUMBER OF SEGMENTS

2

ENTER 1 IF ROTATIONS REQUIRED
ENTER 2 IF TRANSLATION ONLY

2

ENTER X,Y,Z TRANSLATION IN METERS
0.,0.,0.

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

2

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO SAVE FILE AND EXIT

1

ENTER RETURN TO TERMINATE GRAPHICS AND CONTINUE

<CR>

LOAD OBJECT UNITS ARE METRIC

LOAD NUMBER = 1
LOAD COORDINATE SYSTEM ORIGIN
0.00000 0.00000 0.00000
LOAD COORDINATE SYSTEM ORIENTATION
1.00000 0.00000 0.00000
0.00000 1.00000 0.00000
0.00000 0.00000 1.00000

LOAD LENGTH = 0.04000
LOAD RADIUS = 0.01000
LOAD CENTER OF GRAVITY
0.02000 0.00000 0.00000
MASS OF LOAD = 2.00000
LOAD INERTIA MATRIX
0.00010 0.00000 0.00000
0.00000 0.00032 0.00000
0.00000 0.00000 0.00032
NUMBER OF POINT MASSES = 0

ENTER RETURN TO CONTINUE

<CR>

DO YOU WISH TO
1 MODIFY CURRENT LOAD DATA
2 CONTINUE

2

DO YOU WISH TO
1 MODIFY GRAPHICS REPRESENTATION FOR LOAD 1
2 CONTINUE

2

DEFINITION OF LOAD 2

ENTER THE WORLD X, Y, Z COORDINATES DEFINING
THE ORIGIN OF THE LOAD LOCAL COORDINATE SYSTEM
THESE DISTANCES SHOULD BE INPUT IN METERS
0.05,0.05,0.05

SPECIFY ROTATION SEQUENCE FOR ORIENTATION
OF LOAD COORDINATE SYSTEM WITH RESPECT TO
THE WORLD COORDINATE SYSTEM

THE SEQUENCE IS SPECIFIED BY A SERIES OF
ROTATION AXIS/ROTATION ANGLE PAIRS WHERE

1 REPRESENTS THE X AXIS

2 REPRESENTS THE Y AXIS

3 REPRESENTS THE Z AXIS

A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION

1

ENTER 1ST ROTATION ANGLE (DEG)

0.

ENTER 1 TO SPECIFY ANOTHER AXIS/ANGLE PAIR
ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT

2

SPECIFY LENGTH OF LOAD 2 IN METERS
THE FIRST END IS AT THE LOAD COORDINATE SYSTEM
ORIGIN. CENTERLINE OF LOAD IS ALONG X AXIS
SO THE LENGTH WILL DEFINE THE SECOND END

0.04

SPECIFY RADIUS OF LOAD 2 IN METERS
FOR USE IN INERTIA CALCULATIONS

0.015

SPECIFY CENTER OF MASS LOCATION FOR LOAD 2
IN ITS OWN LOCAL COORDINATE SYSTEM

ENTER 1 TO HAVE PROGRAM COMPUTE CENTER OF MASS
ENTER 2 TO REQUEST USER INPUT OF CENTER OF MASS

1

1. SPECIFY MASS OF LOAD 2 IN KILOGRAMS

SPECIFY INERTIA MATRIX FOR LOAD 2

ENTER 1 TO HAVE PROGRAM COMPUTE INERTIA MATRIX
 ENTER 2 TO REQUEST USER INPUT OF INERTIA MATRIX

1

ENTER 1 TO SPECIFY POINT MASSES FOR LOAD 2
 ENTER 2 NOT TO SPECIFY POINT MASSES FOR LOAD 2

2

INPUT SPAN OF LOAD OBJECT SETTING IN METERS
 FOR SCALING GRAPHICS

1.5

SELECT SHAPE

- 1 = CYLINDER
- 2 = CONE
- 3 = RECTANGULAR SOLID
- 4 = SYM TRAPEZOID
- 5 = NONSYM TRAPEZOID
- 6 = TRIANGULAR STRUCTURE
- 7 = DATA TABLET STRUCTURE
- 8 = FILLET
- 9 = NONPLANAR ENTITY

ENTER INTEGER CHOICE

1

ENTER DIAMETER IN METERS

0.03

ENTER LENGTH IN METERS

0.01

ENTER 1 IF ROTATIONS REQUIRED
 ENTER 2 IF TRANSLATION ONLY

1

ENTER AXIS OF ROTATION

- 1 = X-AXIS
- 2 = Y-AXIS
- 3 = Z-AXIS

3

ENTER ROTATION ANGLE, IN DEGREES

90.

ENTER 1 TO SPECIFY ANOTHER ROTATION
 ENTER 2 TO TERMINATE ROTATION INPUT

2

ENTER X,Y,Z TRANSLATION IN METERS

0.,0.,0.

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

2

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO SAVE FILE AND EXIT

1

SELECT SHAPE
1 = CYLINDER
2 = CONE
3 = RECTANGULAR SOLID
4 = SYM TRAPEZOID
5 = NONSYM TRAPEZOID
6 = TRIANGULAR STRUCTURE
7 = DATA TABLET STRUCTURE
8 = FILLET
9 = NONPLANAR ENTITY
ENTER INTEGER CHOICE

1

ENTER DIAMETER IN METERS
0.015

ENTER LENGTH IN METERS
0.03

ENTER 1 IF ROTATIONS REQUIRED
ENTER 2 IF TRANSLATION ONLY

1

ENTER AXIS OF ROTATION
1 = X-AXIS
2 = Y-AXIS
3 = Z-AXIS

3

ENTER ROTATION ANGLE, IN DEGREES
90.

ENTER 1 TO SPECIFY ANOTHER ROTATION
ENTER 2 TO TERMINATE ROTATION INPUT

2

ENTER X,Y,Z TRANSLATION IN METERS
0.,0.01,0.

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CHANGE CURRENT COMPONENT
ENTER 2 IF COMPONENT IS CORRECT

2

ENTER 1 TO DEFINE ANOTHER COMPONENT
ENTER 2 TO SAVE FILE AND EXIT

2

ENTER RETURN TO TERMINATE GRAPHICS AND CONTINUE

<CR>

LOAD OBJECT UNITS ARE METRIC

LOAD NUMBER = 2
LOAD COORDINATE SYSTEM ORIGIN
0.05000 0.05000 0.05000
LOAD COORDINATE SYSTEM ORIENTATION
1.00000 0.00000 0.00000
0.00000 1.00000 0.00000
0.00000 0.00000 1.00000

LOAD LENGTH = 0.04000
LOAD RADIUS = 0.01500
LOAD CENTER OF GRAVITY
0.02000 0.00000 0.00000
MASS OF LOAD = 1.00000
LOAD INERTIA MATRIX
0.00011 0.00000 0.00000
0.00000 0.00019 0.00000
0.00000 0.00000 0.00019
NUMBER OF POINT MASSES = 0

ENTER RETURN TO CONTINUE

<CR>

DO YOU WISH TO
1 MODIFY CURRENT LOAD DATA
2 CONTINUE
2

DO YOU WISH TO
1 MODIFY GRAPHICS REPRESENTATION FOR LOAD 2
2 CONTINUE
2

ENTER NAME OF FILE TO SAVE LOAD DATA IN
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CANNOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANNER.LOD
PLANAR.LOD

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE/MODIFY ARM DATA FILE
2	CREATE/MODIFY DETAILED ENVIRONMENT
3	CREATE/MODIFY LOAD OBJECTS FILE
4	CREATE SYSTEM DATA FILE
5	TERMINATE SYSTEM DEFINITION EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

5

EXITING FROM SYSTEM DEFINITION FUNCTION

ROBOTIC SYSTEM SIMULATION PROGRAM (ROSSIM)
SYSTEM DEFINITION - LOAD OBJECTS REPRESENTATION

MARTIN MARIETTA

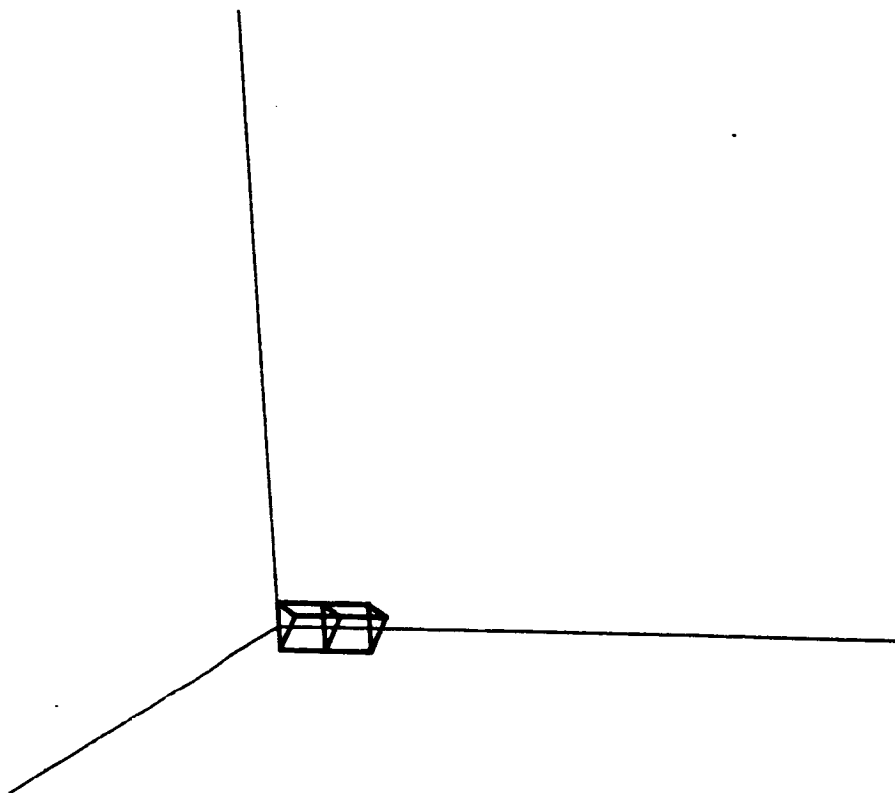


Figure A-27. - Completion of load 1 in detailed load object file.

ROBOTIC SYSTEM SIMULATION PROGRAM (ROSSIM)
SYSTEM DEFINITION - LOAD OBJECTS REPRESENTATION

MARTIN MARIETTA

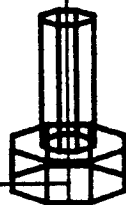


Figure A-23. - Completion of load 2 in detailed load object file.

Procedure for Creating a Total Robotic System Workcell

This process is in charge of building a system by putting together previously defined arms and, optionally, loads and an environment. There is allowance for only one environment file, one load objects file and a preset maximum number of arm data files. Only metric or English units are allowed as I/O specifications for locations of arms and loads.

The determination of construction in conjunction with the Evans and Sutherland graphics display is via terminal input:

```
*****  
**** ROBOTIC SYSTEM DEFINITION ****  
*****
```

```
SPECIFY WHETHER GRAPHICS ARE DESIRED  
DURING SYSTEM DEFINITION
```

```
ENTER 1 FOR NO GRAPHICS  
ENTER 2 FOR GRAPHICS
```

For redefinition of the input/output units to be assumed in the system creation phase, the header and prompt are:

ENVIRONMENT DEFINITION

```
WHICH UNITS DO YOU WISH TO USE FOR I/O?  
ENTER 1 FOR METRIC UNITS  
ENTER 2 FOR ENGLISH UNITS
```

The user may define the system initial setup and the values of the constant parameters in the world scenario that effect the manipulator performance. The interactive input properties of the system environment are for use in the analysis tools functions and currently include acceleration due to gravity and the overall system operation size.

The prompt to answer for modification of the standard gravity default value appears as:

```
DO YOU WISH STANDARD GRAVITY?  
ENTER 1 FOR STANDARD GRAVITY:  0.0  9.8  0.0 METERS/S**2  
                               or 0.0 386.1 0.0 INCHES/S**2  
ENTER 2 TO INPUT NEW GRAVITY
```

The prechosen math units typing will be written to the screen as a reminder and for the convenience of the user when entering the system values. The format is:

UNITS FOR INPUT/OUTPUT ARE AS FOLLOWS:

LENGTH	METERS
VELOCITY	METERS/SEC
ACCELERATION	METERS/S**2
MASS	KILOGRAMS
INERTIA	KG-M**2
FORCE	NEWTONS
TORQUE	N-M

or

UNITS FOR INPUT/OUTPUT ARE AS FOLLOWS:

LENGTH	INCHES
VELOCITY	INCHES/SEC
ACCELERATION	INCHES/S**2
MASS	POUNDS(MASS)
INERTIA	LBM-IN**2
FORCE	POUNDS(FORC)
TORQUE	IN-LBF

The total span that will incorporate all of the system constituent files to be included is given with the value used in scaling the graphics:

ENTER THE SYSTEM SPAN (IN [length units]) FOR GRAPHICS
THE GRAPHICS ARE SCALED SUCH THAT THIS
SPAN FITS IN ONE HALF OF THE GRAPHICS SCREEN

Again in the system building routine, the inquiry entails the constituent files desired for this particular system. The first option entails:

DO YOU WISH A DETAILED SYSTEM ENVIRONMENT?
1 NO DETAILED ENVIRONMENT
2 INCLUDE DETAILED ENVIRONMENT

If one opts to include an environment, the routine that reads this file asks for the name of the existing file to include:

ENTER FILENAME OF ENVIRONMENT DATA
TO BE READ. FILE MUST CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLNSYS.ENV

Also, when constructing the system, the desired number of arm files to include should be input. Each will initially be read into the system profile in the same orientation in which they were saved. Enter the integer:

SYSTEM DEFINITION ROUTINE

ENTER NUMBER OF ARMS IN SYSTEM

Then in the read arms loop, for each arm input:

ENTER FILENAME OF ARM DATA FILE FOR ARM J
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANDET.ARM

In the system building session, the freedom to change an arm base placement in the system scenario is accomplished with the flag:

DO YOU WISH TO MODIFY THE BASE LOCATION
OR ORIENTATION FOR ARM NUMBER J?
1 NO MODIFICATION
2 MODIFY BASE LOCATION OR ORIENTATION

From the subroutine that allows placement of the input arm into the correct location and orientation needed for this system, the current location values resident in the array are printed to the terminal. The user responds to the observed assignments with:

DO YOU WISH TO MODIFY THE
BASE LOCATION FOR ARM J?
ENTER 1 FOR NO MODIFICATION
ENTER 2 TO INPUT NEW LOCATION

If changing the location, input in world coordinates:

ENTER NEW BASE LOCATION FOR ARM J
(ENTER THREE REAL NUMBERS) IN [length units]

From the system building routine the user is questioned, after the current values are shown on the screen, for the new arm orientation, if desired:

DO YOU WISH TO MODIFY THE
BASE ORIENTATION FOR ARM J?
THE INPUT ROTATION WILL BE CONCATENATED
WITH THE CURRENT ARM ORIENTATION
ENTER 1 FOR NO MODIFICATION
ENTER 2 TO INPUT NEW ORIENTATION

If changing the orientation specification, the rotations are about the current unit vector directions of the arm base coordinate axes are given with the answer to:

SPECIFY ROTATION SEQUENCE FOR ORIENTATION
OF BASE SYSTEM WITH RESPECT TO WORLD SYSTEM
SEQUENCE IS SPECIFIED BY A SERIES OF
ROTATION AXIS/ROTATION ANGLE PAIRS WHERE

- 1 REPRESENTS THE X AXIS
- 2 REPRESENTS THE Y AXIS
- 3 REPRESENTS THE Z AXIS

A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION

ENTER 1ST ROTATION ANGLE, IN DEGREES

ENTER 1 TO SPECIFY ANOTHER ROTATION

ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT

If the user is still not satisfied with the current arm state in the system, other modifications are allowed through:

ENTER 1 TO CONTINUE

ENTER 2 TO MODIFY ARM J LOCATION
OR ORIENTATION

Then answer the flag to include load objects in the system file:

DO YOU WISH TO ADD LOAD OBJECTS TO THE SYSTEM ?

- 1 NO LOAD OBJECTS IN CURRENT SYSTEM
- 2 READ IN AND USE A LOAD OBJECTS DATA FILE

For the selection to include a load objects file:

ENTER THE NAME OF THE FILE CONTAINING LOAD DATA
THE TOTAL NUMBER OF CHARACTERS IN THE FILENAME
CANNOT EXCEED 40

EXAMPLE - ROBDEVICE:[ROBDIR]PLANDET.LOD

When the user is in the process of choosing the point of fixation and arrangement, or configuration, for the load objects:

ENTER 1 TO CONTINUE

ENTER 2 TO MODIFY LOAD OBJECT J LOCATION
OR ORIENTATION

The current load location will be written for the user at this point. For movement of the load objects to another locale:

ENTER NEW LOCATION FOR LOAD J
(ENTER THREE REAL NUMBERS WITH UNITS OF [length units])

Next, the current rotation orientation matrix values are given at the terminal. The flag for rotation changes of the current load appears as:

DO YOU WISH TO MODIFY THE
LOAD ORIENTATION FOR LOAD J?
ENTER 1 FOR NO MODIFICATION
ENTER 2 TO INPUT NEW ORIENTATION

If opting to modify the orientation scheme:

SPECIFY ROTATION SEQUENCE FOR ORIENTATION
OF LOAD SYSTEM WITH RESPECT TO WORLD SYSTEM
SEQUENCE IS SPECIFIED BY A SERIES OF
ROTATION AXIS/ROTATION ANGLE PAIRS WHERE

- 1 REPRESENTS THE X AXIS
- 2 REPRESENTS THE Y AXIS
- 3 REPRESENTS THE Z AXIS

A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION

and

ENTER 1ST ROTATION ANGLE, IN DEGREES

and

ENTER 1 TO SPECIFY ANOTHER ROTATION

ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT

The transformation matrices between neighboring joint coordinate systems and between joint and base systems, and the vectors describing tool location and link locations are transformed into world coordinates. Also, the locations and orientations for any loads being held by any of the arms, are determined in the world coordinate system. (Note that no state orientation misalignment is currently implemented.) Hence, the system Jacobian matrix will be invented with the tool/joint/base to world transformation matrices, and used later in the simulation capabilities while solving for individual joint velocities for each arm.

To terminate the graphics, if in effect during the building of the robotic system:

ENTER RETURN TO TERMINATE GRAPHICS AND CONTINUE

Arguments are passed to the graphics and the system object data loading routines for indication of the intended number of arms in the system, the existence of environment data and a specification for including a load objects file. The graphics in the system creation uses the system span input by the user earlier to scale the display. The graphics will be initialized in a

constant state as it appeared at creation. Also during modification of the display data for constituent data files, the environment is constant and therefore cannot be updated. As before, the Evans and Sutherland graphics routines are used to provide all displays.

The form of the display for the manipulator display on the E&S graphics unit is enhanced by borders and text output locations with the robotic simulation title, current simulation time, creation mode title and joint travel status data column headings. The form will only allow two arms worth of column output information (joint travel angles and percent of the maximum traveled for each joint). The initial state information is displayed here during the system definition function.

The system definition function writes the unformatted data ('.SYS') file containing the contents of pertinent COMMON blocks defining the graphics, geometry, and mass properties of the total robotic system. The user is prompted for the file name under which the file is to be stored.

```
ENTER FILENAME OF SYSTEM DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANAR.SYS
```

SYSTEM DATA FILE HAS BEEN WRITTEN

Sample run. - A sample total system creation (Example A-7) run is provided along with the resultant graphic pictures obtained during the execution (Fig. A-29 through A-31).

Example A-7

ROBOTIC SYSTEM SIMULATION PROGRAM (ROBSIM)

ENTERING SYSTEM DEFINITION FUNCTION

DEFAULT LOGICAL UNIT ASSIGNMENTS USED WITHIN ROBSIM

LU	USE
5	READ UNIT (TERMINAL)
6	WRITE UNIT (TERMINAL)
7	PRINTED OUTPUT UNIT
8-9	SIMULATION INPUT FILE
10	SIMULATION OUTPUT FILE
11	ACTUATOR PARAMETERS INPUT FILE
14	LOAD OBJECTS DATA FILE
15	ERROR MESSAGE FILE
16	GAIN CONSTANTS FILE
17	TORQUE DATA INPUT FILE
18	ACC-VEL-THETA FILE
19	PROGRAMS OPTIONS FILE
20	PLOT DATA FILE
21	MOTION TIME HISTORY FILE
22	HARDWARE CONTROL SIGNALS
23	CONTROL OPTIONS INPUT FILE
24	CONTROL MODULE OUTPUT FILE

USER WILL BE PROMPTED FOR FILENAMES
TO ASSOCIATE WITH EACH LOGICAL UNIT
WHEN REQUIRED

ENTER RETURN TO CONTINUE

<CR>

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE/MODIFY ARM DATA FILE
2	CREATE/MODIFY DETAILED ENVIRONMENT
3	CREATE/MODIFY LOAD OBJECTS FILE
4	CREATE SYSTEM DATA FILE
5	TERMINATE SYSTEM DEFINITION EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

4

**** ROBOTIC SYSTEM DEFINITION ****

SPECIFY WHETHER GRAPHICS ARE DESIRED
DURING SYSTEM DEFINITION

ENTER 1 FOR NO GRAPHICS
ENTER 2 FOR GRAPHICS

2

ENVIRONMENT DEFINITION

WHICH UNITS DO YOU WISH TO USE FOR I/O?
ENTER 1 FOR METRIC UNITS
ENTER 2 FOR ENGLISH UNITS

1

UNITS FOR INPUT/OUTPUT ARE AS FOLLOWS:

LENGTH	METERS
VELOCITY	METERS/SEC
ACCELERATION	METERS/S**2
MASS	KILOGRAMS
INERTIA	KG-M**2
FORCE	NEWTONS
TORQUE	N-M

DO YOU WISH STANDARD GRAVITY?
ENTER 1 FOR STANDARD GRAVITY: 0.0 9.8 0.0 METERS/S**2
ENTER 2 TO INPUT NEW GRAVITY

1

ENTER THE SYSTEM SPAN (IN METERS) FOR GRAPHICS
THE GRAPHICS ARE SCALED SUCH THAT THIS
SPAN FITS IN ONE HALF OF THE GRAPHICS SCREEN

1.5

DO YOU WISH A DETAILED SYSTEM ENVIRONMENT?
1 NO DETAILED ENVIRONMENT
2 INCLUDE DETAILED ENVIRONMENT

2

ENTER FILENAME OF ENVIRONMENT DATA
TO BE READ. FILE MUST CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLNSYS.ENV
PLANAR.ENV

ENVIRONMENT DATA FILE HAS BEEN READ
ALL COMMON BLOCKS ARE SAVED

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
<<CR>=NONE) :

<CR>

SYSTEM DEFINITION ROUTINE

ENTER NUMBER OF ARMS IN SYSTEM

1

ENTER FILENAME OF ARM DATA FILE FOR ARM 1
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40

EXAMPLE - ROBDEVICE:[ROBDIR]PLANDET.ARM
PLNDET.ARM

ARM DATA FILE FOR ARM 1 HAS BEEN READ

DO YOU WISH TO MODIFY THE BASE LOCATION
OR ORIENTATION FOR ARM NUMBER 1?

- 1 NO MODIFICATION
- 2 MODIFY BASE LOCATION OR ORIENTATION

2

CURRENT BASE LOCATION FOR ARM 1 IS

BASLOC = 0.00000 0.00000 0.00000

DO YOU WISH TO MODIFY THE
BASE LOCATION FOR ARM 1?
ENTER 1 FOR NO MODIFICATION
ENTER 2 TO INPUT NEW LOCATION

2

ENTER NEW BASE LOCATION FOR ARM 1
(ENTER THREE REAL NUMBERS) IN METERS
0.75,0.05,0.

ROTATION MATRIX RELATING BASE TO WORLD
COORDINATES FOR ARM 1 IS

0.00000	-1.00000	0.00000
1.00000	0.00000	0.00000
0.00000	0.00000	1.00000

DO YOU WISH TO MODIFY THE
BASE ORIENTATION FOR ARM 1?
THE INPUT ROTATION WILL BE CONCATENATED
WITH THE CURRENT ARM ORIENTATION
ENTER 1 FOR NO MODIFICATION
ENTER 2 TO INPUT NEW ORIENTATION

2

SPECIFY ROTATION SEQUENCE FOR ORIENTATION
OF BASE SYSTEM WITH RESPECT TO WORLD SYSTEM
SEQUENCE IS SPECIFIED BY A SERIES OF
ROTATION AXIS/ROTATION ANGLE PAIRS WHERE

- 1 REPRESENTS THE X AXIS
- 2 REPRESENTS THE Y AXIS
- 3 REPRESENTS THE Z AXIS

A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION
1
ENTER 1ST ROTATION ANGLE, IN DEGREES
180.

ENTER 1 TO SPECIFY ANOTHER ROTATION
ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT
2

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CONTINUE
ENTER 2 TO MODIFY ARM 1 LOCATION
OR ORIENTATION

1
DO YOU WISH TO ADD LOAD OBJECTS TO THE SYSTEM ?
1 NO LOAD OBJECTS IN CURRENT SYSTEM
2 READ IN AND USE A LOAD OBJECTS DATA FILE
2

ENTER THE NAME OF THE FILE CONTAINING LOAD DATA
THE TOTAL NUMBER OF CHARACTERS IN THE FILENAME
CANNOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANDET.LOD
PLANAR.LOD

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CONTINUE
ENTER 2 TO MODIFY LOAD OBJECT 1 LOCATION
OR ORIENTATION

2

CURRENT LOCATION FOR LOAD 1 IN METERS

LOAD LOC = 0.00000 0.00000 0.00000

ENTER NEW LOCATION FOR LOAD 1

(ENTER THREE REAL NUMBERS WITH UNITS OF METERS)
0.1,0.05,0.

ROTATION MATRIX RELATING LOAD TO WORLD
COORDINATES FOR LOAD 1 IS

1.00000	0.00000	0.00000
0.00000	1.00000	0.00000
0.00000	0.00000	1.00000

DO YOU WISH TO MODIFY THE
LOAD ORIENTATION FOR LOAD 1?
ENTER 1 FOR NO MODIFICATION
ENTER 2 TO INPUT NEW ORIENTATION

2

SPECIFY ROTATION SEQUENCE FOR ORIENTATION
OF LOAD SYSTEM WITH RESPECT TO WORLD SYSTEM
SEQUENCE IS SPECIFIED BY A SERIES OF
ROTATION AXIS/ROTATION ANGLE PAIRS WHERE

1 REPRESENTS THE X AXIS
2 REPRESENTS THE Y AXIS
3 REPRESENTS THE Z AXIS

A MAXIMUM OF 3 ROTATIONS ARE ALLOWED

ENTER 1ST AXIS OF ROTATION

1

ENTER 1ST ROTATION ANGLE, IN DEGREES

90.

ENTER 1 TO SPECIFY ANOTHER ROTATION
ENTER 2 TO TERMINATE ROTATION SEQUENCE INPUT

2

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(<CR>=NONE) :

<CR>

ENTER 1 TO CONTINUE
ENTER 2 TO MODIFY LOAD OBJECT 1 LOCATION
OR ORIENTATION

1

*** E&S DIALS CONTROL OF GRAPHICS ***
*** DISPLAY IS NOW ENGAGED ***

DEPRESS FUNCTION SWITCH 31 TO DISENGAGE
THE GRAPHICS LOOP AND CONTINUE

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(**<CR>**=NONE) :

<CR>

ENTER 1 TO CONTINUE
ENTER 2 TO MODIFY LOAD OBJECT 2 LOCATION
OR ORIENTATION

1

ENTER RETURN TO TERMINATE GRAPHICS AND CONTINUE

<CR>

ENTER FILENAME OF SYSTEM DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANAR.SYS
PLNDET.SYS

SYSTEM DATA FILE HAS BEEN WRITTEN

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	CREATE/MODIFY ARM DATA FILE
2	CREATE/MODIFY DETAILED ENVIRONMENT
3	CREATE/MODIFY LOAD OBJECTS FILE
4	CREATE SYSTEM DATA FILE
5	TERMINATE SYSTEM DEFINITION EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

5

EXITING FROM SYSTEM DEFINITION FUNCTION

FORTRAN STOP

INPUT (Y) TO RUN SYSTEM DEFINITION FUNCTION AGAIN, (OTHERWISE, RETURN) **<CR>**
INPUT (Q) IF YOU WISH TO EXIT THE PROGRAM (OTHERWISE, RETURN)Q

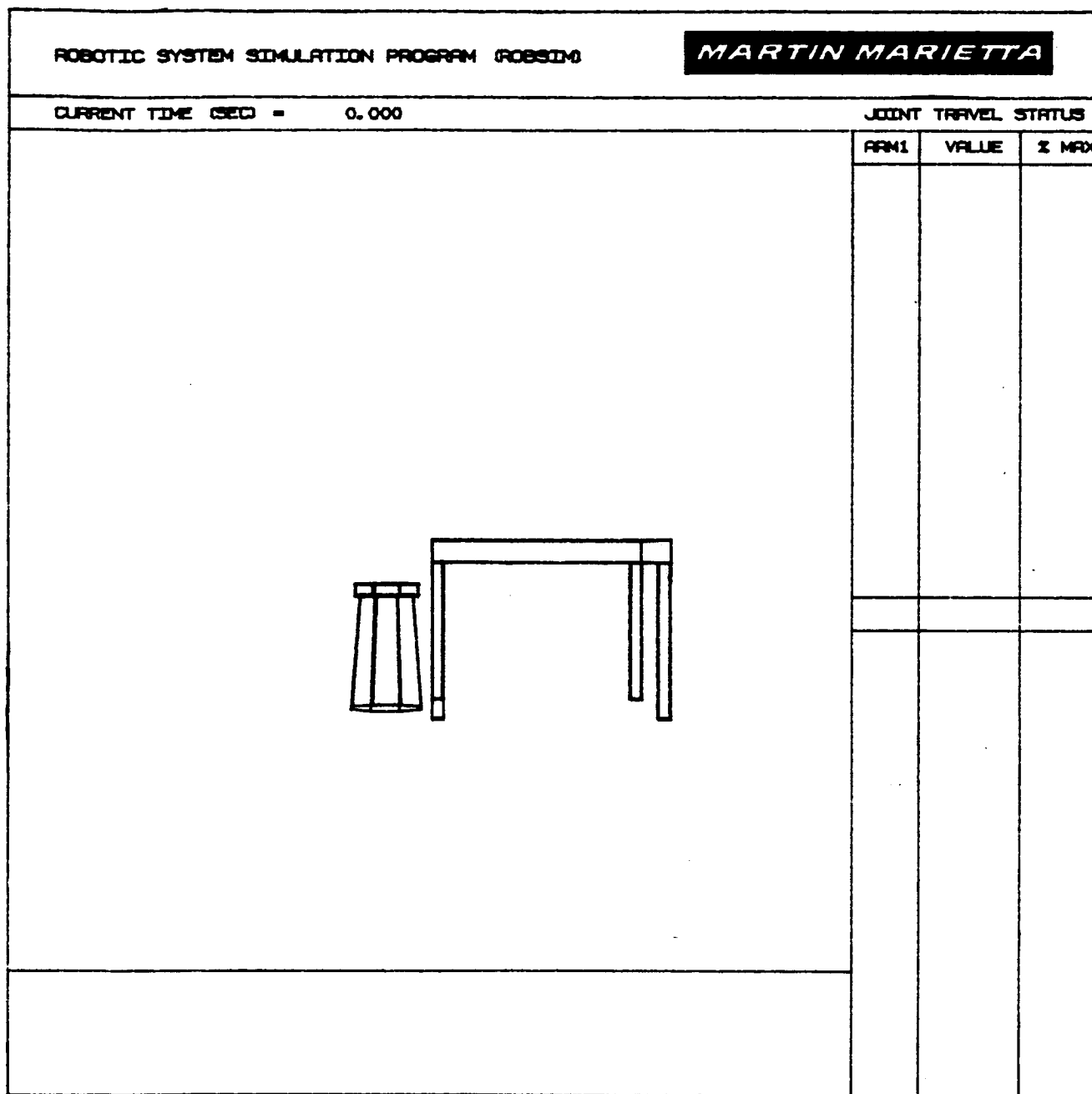


Figure A-29. - Environment display during robotic system creation.

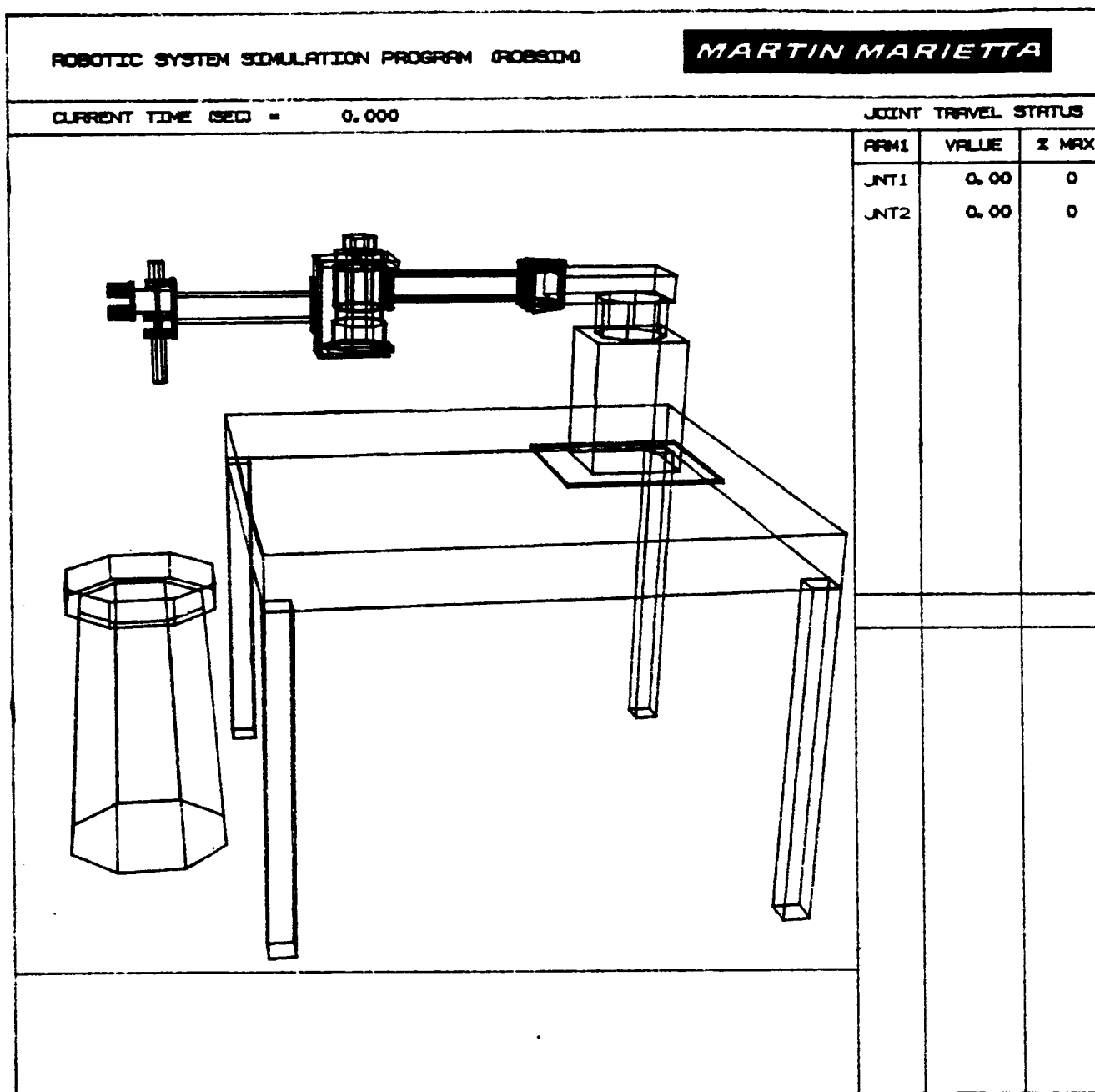


Figure A-30. - Arm insertion during robotic system creation.

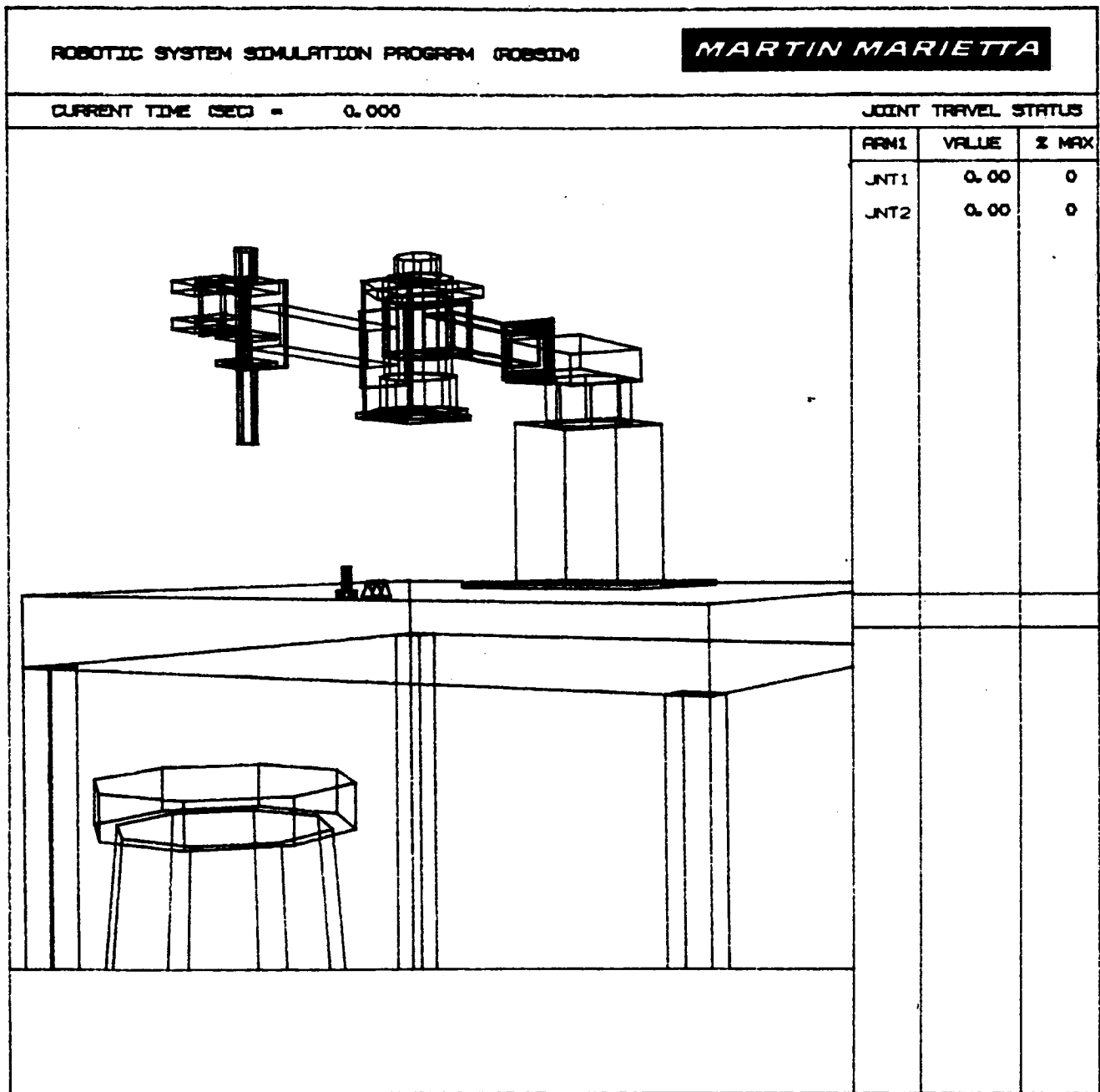


Figure A-31. - Complete robotic planar arm system.

THE ANALYSIS TOOLS USER'S GUIDE

This portion of the user's guide describes the use of the analysis tools function of ROBSIM that carry out kinematic analysis, requirements analysis, and response simulation. It should be noted that before using this section a manipulator arm system must have been completely defined using the system definition function of ROBSIM.

At this point, a header and table listing logical unit number assignments is displayed. Pressing the RETURN key will continue program execution and show the menu of SIMDRVR options:

SELECTION MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REQUIREMENTS ANALYSIS WITHOUT GRAPHICS
2	REQUIREMENTS ANALYSIS WITH GRAPHICS
3	RESPONSE SIMULATION WITHOUT GRAPHICS
4	RESPONSE SIMULATION WITH GRAPHICS
5	SET UP A MOTION PROGRAM
6	TERMINATE ANALYSIS TOOLS EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

The user should enter the mode number corresponding to the option desired.

At this point the discussion is separated into subsections based on the menu options listed. Modes 1 and 2 are discussed in the requirements analysis subsection. These options are identical with the exception that the Evans and Sutherland graphics display accompanies execution in mode 2. Likewise, modes 3 and 4 are identical and are discussed in the response simulation subsection. Mode 5, which sets up a motion program or specifies the manipulator motion, is discussed in the motion profile subsection. Mode 6 exits this section of ROBSIM and returns the user to the executive command file level.

Requirements Analysis

This subsection documents the use of the requirements analysis mode of the SIMDRVR portion of ROBSIM. Requirements analysis with and without graphics (Mode 1 and Mode 2) will be discussed together because the analysis carried out in both modes is identical. The underlying formulation for this analysis is described in the analysis capabilities section of the main text. Mode 2, however, displays the motion of the manipulator system on an Evans and Sutherland picture system. This display also includes the current time and a table of displacements and percent of maximum allowable travel for each joint.

The user must first specify the name of the file containing the manipulator system definition in response to the prompt:

ENTER FILENAME OF SYSTEM DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - DRD1:[ROBSIM]PLNRARM.SYS

If the prescribed file is read in without any problems, the following verification is printed:

SYSTEM DATA FILE AS BEEN READ
ALL COMMON BLOCKS ARE LOADED

Requirements run options. The run options define what type of output files will be written during execution, how the run will be controlled, what computations will be done and the duration of program execution. During a requirements analysis run, the program takes the option flags input by the user and writes them to a file. The next time the requirements analysis is run the file is read in and the user is given the choice of using these same options or changing them:

DO YOU WISH TO MODIFY CURRENT OPTIONS?
1 LIST CURRENT OPTIONS
2 MODIFY CURRENT OPTIONS
3 RUN PROGRAM USING CURRENT OPTIONS
(911 FOR THE ROBSIM HELP LIBRARY)

Entering a 1 will produce a listing of the current options similar to that shown:

CURRENT OPTIONS INCLUDE:

PRINT CONDENSED OUTPUT TO REQEX.PRT
EVERY .50000E-01 SEC

PLOT DATA OUTPUT TO REQEX.PLT
EVERY .50000E-01 SEC

DYNAMIC COMPUTATIONS ARE REQUESTED

CURRENT SIMULATION TIMES ARE:

START TIME .00000E+00 SEC
STOP TIME 2.0000 SEC
TIME STEP .50000E-01 SEC

DO YOU WISH TO MODIFY CURRENT OPTIONS?
1 LIST CURRENT OPTIONS
2 MODIFY CURRENT OPTIONS
3 RUN PROGRAM USING CURRENT OPTIONS
(911 FOR THE ROBSIM HELP LIBRARY)

Entering a 2 in response to the options prompt allows the user to interactively define which options should be used. (If no options file exists, this mode is selected by default.) The first output option available is a print option:

```
DO YOU WISH PRINTED OUTPUT?
  1  PRINT OUTPUT
  2  PRINT CONDENSED OUTPUT
  3  NO PRINTED OUTPUT
(911 FOR THE ROBSIM HELP LIBRARY)
```

For each output option selected, the program prompts the user for the name of the file in which to store the information and at what time intervals it should be written:

```
ENTER FILENAME OF PRINTED OUTPUT FILE
TO BE CREATED.  FILE MUST NOT CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - DRDO:[ROBSIM]PLANAR.PRT
```

```
ENTER THE DESIRED TIME STEP FOR THE PRINTED OUTPUT
(ENTER 911 FOR THE ROBSIM HELP LIBRARY)
```

This option does not actually print a file during execution, but writes the analysis data to a formatted file that may subsequently be spooled to a printer. The values saved at each time interval include:

- 1) Time;
- 2) Relative joint displacements;
- 3) Relative joint velocities;
- 4) Relative joint acceleration;
- 5) Actuator driving torque;
- 6) Joint position vectors;
- 7) Linear velocity vector;
- 8) Linear acceleration vector;
- 9) Absolute angular velocity;
- 10) Absolute angular acceleration;
- 11) Local coordinate system to world coordinate system transformations;
- 12) Inertia matrix world coordinates;

- 13) Joint reaction force vector;
- 14) Force vector at the joint/link centroid;
- 15) Joint reaction torque vectors.

The condensed printout saves only the first five variables from the list above.

The next option is for a torque output file:

```
DO YOU WISH TORQUE DATA OUTPUT?
  1  TORQUE OUTPUT
  2  NO TORQUE OUTPUT
(911 FOR THE ROBSIM HELP LIBRARY)
```

The unformatted file written by this option contains time and actuator driving torques for each joint. This file may later be used to drive a response simulation.

The next option determines how the requirements analysis run will be controlled:

```
HOW DO YOU WISH TO CONTROL THE SIMULATION?
  1  READ ACC-VEL-THETA DATA FILE
  2  CONTROL WITH POLYNOMIAL TIME HISTORIES
  3  CONTROL WITH E&S FUNCTION KEYS
(911 FOR THE ROBSIM HELP LIBRARY)
```

For option 1, an acc-vel-theta file must have been previously generated, usually from a response simulation run. This unformatted file contains joint angular accelerations, velocities, and positions as function of time, and the corresponding manipulator motions and loads are determined by these. Option 2, control with polynomial time histories, makes use of the motion profile file written with the use of mode 5 of the SIMDRVR main menu. Setting up a motion profile is described in the motion profile subsection. Control with the Evans and Sutherland function keys, option 3, can be used only when the requirements analysis is being run with graphics. This control uses the dials on the E&S control panels to move any part of the manipulator arm. This is most often used to investigate arm configuration and feasible motions.

The requirements analysis always includes a kinematic analysis of the arm motion. If the user wishes to also evaluate dynamic loads during the motion, this is done by entering a 1 in response to the following prompt:

```
DO YOU WISH DYNAMIC COMPUTATIONS?
  1  DO DYNAMICS COMPUTATIONS
  2  NO DYNAMICS
(911 FOR THE ROBSIM HELP LIBRARY)
```

Two additional output options are also available:

DO YOU WISH A SIMULATION OUTPUT FILE?

1 WRITE SIMULATION FILE

2 NO SIMULATION FILE

(911 FOR THE ROBSIM HELP LIBRARY)

A response of 1 to this prompt indicates that an unformatted file of joint angles as functions of time is to be saved during the requirements run. This file can then be used in the ROBSIM postprocessor to play back the motion that occurred during the requirements analysis. The last file the user has the option of writing is a plot file:

DO YOU WISH A PLOT DATA OUTPUT FILE?

1 SAVE A PLOT DATA FILE

2 NO PLOT DATA FILE

(911 FOR THE ROBSIM HELP LIBRARY)

If plotting is requested, various parameters are saved for subsequent display on a hardcopy plotter or graphics terminal. Plotting is performed by the post-processor function of ROBSIM (POSTDRV). Five different plotting packages are available for use with the requirements analysis. The packages and variables saved in each are listed:

- 1) Brief - joint position (angular),
 - joint angular velocity,
 - joint angular acceleration,
 - joint actuator torque;
- 2) End effector - end effector x position,
 - end effector y position,
 - end effector z position,
 - end effector x force,
 - end effector y force,
 - end effector z force,
 - end effector x torque,
 - end effector y torque,
 - end effector z torque;
- 3) Joint positions - joint x position,
 - joint y position,
 - joint z position;
- 4) Reaction forces - joint force, x - direction,
 - joint force, y - direction,
 - joint force, z - direction,
 - joint torque, x - direction,
 - joint torque, y - direction,
 - joint torque, z - direction;
- 5) All of the above.

At this point in the program the user is asked for a file name under which the data will be saved and a write interval. At a later point, the user is asked which package of values to save.

The last part of the program options asks the user for start and stop times and how often the analysis calculations should be carried out:

ENTER PROGRAM START TIME (SEC)
(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

ENTER PROGRAM STOP TIME (SEC)
(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

ENTER PROCESSING STEPSIZE (SEC)
(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

If the manipulator motion is being controlled with the Evans and Sutherland dials, the stop time should be set to a very large number. When the user has finished, there is a button on the E&S control panel to terminate the motion.

If all the options have been entered correctly, the user should enter a 3 when the following menu is displayed:

DO YOU WISH TO MODIFY CURRENT OPTIONS?
1 LIST CURRENT OPTIONS
2 MODIFY CURRENT OPTIONS
3 RUN PROGRAM USING CURRENT OPTIONS
(911 FOR THE ROBSIM HELP LIBRARY)

If a motion profile is to be used to control the manipulator, the user is now prompted to enter the name of the file containing the data:

ENTER THE FILENAME CONTAINING THE MOTION PROFILE FOR ARM 1
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - DRDO:[ROBSIM]MOPROF.THP

If the plot file option was selected, the user now must also prescribe the desired plot package in response to the following prompt:

CHOOSE ONE OF THE FOLLOWING PLOT PACKAGES TO WRITE TO A FILE

1. THE BRIEF PACKAGE CONTAINING:
ENTRY 1 IS THE THETA VALUE
ENTRY 2 IS THE THETA DOT VALUE
ENTRY 3 IS THE THETA DOUBLE DOT VALUE
ENTRY 4 IS THE ACTUATOR TORQUE VALUE

ENTER INTEGER PLOT PACKAGE NUMBER TO CHOOSE A PACKAGE
OR ENTER RETURN TO CONTINUE

2. THE END-EFFECTOR PACKAGE CONTAINING:

ENTRY 1 IS THE END EFF. X POSITION
ENTRY 2 IS THE END EFF. Y POSITION
ENTRY 3 IS THE END EFF. Z POSITION
ENTRY 4 IS THE END EFF. X FORCE
ENTRY 5 IS THE END EFF. Y FORCE
ENTRY 6 IS THE END EFF. Z FORCE
ENTRY 7 IS THE END EFF. X TORQUE
ENTRY 8 IS THE END EFF. Y TORQUE
ENTRY 9 IS THE END EFF. Z TORQUE

ENTER INTEGER PLOT PACKAGE NUMBER TO CHOOSE A PACKAGE
OR ENTER RETURN TO CONTINUE

3. THE JOINT POSITIONS PACKAGE CONTAINING:

ENTRY 1 IS THE JOINT X POSITION VALUE
ENTRY 2 IS THE JOINT Y POSITION VALUE
ENTRY 3 IS THE JOINT Z POSITION VALUE

ENTER INTEGER PLOT PACKAGE NUMBER TO CHOOSE A PACKAGE
OR ENTER RETURN TO CONTINUE

4. THE REACTION FORCES PACKAGE CONTAINING:

ENTRY 1 IS THE JOINT FORCE X VALUE
ENTRY 2 IS THE JOINT FORCE Y VALUE
ENTRY 3 IS THE JOINT FORCE Z VALUE
ENTRY 4 IS THE JOINT TORQUE X VALUE
ENTRY 5 IS THE JOINT TORQUE Y VALUE
ENTRY 6 IS THE JOINT TORQUE Z VALUE

ENTER INTEGER PLOT PACKAGE NUMBER TO CHOOSE A PACKAGE
OR ENTER RETURN TO CONTINUE

5. THE COMBINATION BRIEF/END-EFFECTOR/JOINT POSITIONS/REACTION FORCES
PACKAGE CONTAINING:

ENTRY 1 IS THE THETA VALUE
ENTRY 2 IS THE JOINT X POS. VALUE
ENTRY 3 IS THE JOINT Y POS. VALUE
ENTRY 4 IS THE JOINT Z POS. VALUE
ENTRY 5 IS THE THETA DOT VALUE
ENTRY 6 IS THE THETA DOUBLE DOT VALUE
ENTRY 7 IS THE JOINT X FORCE VALUE
ENTRY 8 IS THE JOINT Y FORCE VALUE
ENTRY 9 IS THE JOINT Z FORCE VALUE
ENTRY 10 IS THE JOINT X TORQUE VALUE
ENTRY 11 IS THE JOINT Y TORQUE VALUE
ENTRY 12 IS THE JOINT Z TORQUE VALUE
ENTRY 13 IS THE ACTUATOR TORQUE VALUE
ENTRY 14 IS THE END-EFF. X POSITION
ENTRY 15 IS THE END-EFF. Y POSITION
ENTRY 16 IS THE END-EFF. Z POSITION

ENTRY 17 IS THE END-EFF. X FORCE
ENTRY 18 IS THE END-EFF. Y FORCE
ENTRY 19 IS THE END-EFF. Z FORCE
ENTRY 20 IS THE END-EFF. X TORQUE
ENTRY 21 IS THE END-EFF. Y TORQUE
ENTRY 22 IS THE END-EFF. Z TORQUE

ENTER INTEGER PLOT PACKAGE NUMBER TO CHOOSE A PACKAGE
OR ENTER RETURN TO CONTINUE

SELECT PLOT PACKAGE DESIRED FOR SAVE

NUMBER	PACKAGE
1	BRIEF PACKAGE
2	END-EFFECTOR PACKAGE
3	JOINT POSITION PACKAGE
4	REACTION FORCES PACKAGE
5	COMBINATION OF ABOVE PACKAGES
6	TO WRITE DESCRIPTIONS AGAIN

ENTER INTEGER VALUE FOR MODE DESIRED

Execution of requirements analysis will begin after all the prompts have been answered. As execution proceeds, the current analysis time is displayed on the user's terminal for general information. During execution with graphics, the user may stop the manipulator motion at any time to observe the system. This is done by pressing the first button on the E&S control panel. The manipulator system display may then be moved or rotated to obtain a different perspective. To resume program execution, press the first button on the control panel again.

Sample run. - Example A-8 illustrates the use of the ROBSIM requirements analysis without graphics. The user wants to control a planar arm with a previously defined motion profile. Desired outputs are a condensed printout and plots of joint positions as functions of time.

Example A-8

```
$ @ROBSIM
INPUT (INITDRV) --TO RUN ROBSIM SYSTEM DEFINITION FUNCTION
      (SIMDRV)  --TO RUN ROBSIM SIMULATION ANALYSIS TOOLS FUNCTION
      (POSTDRV) --TO RUN ROBSIM POST PROCESSOR FUNCTION
WHICH:SIMDRV
Previous logical name assignment replaced
Previous logical name assignment replaced
```

ROBOTIC SYSTEM SIMULATION PROGRAM (ROBSIM)

ENTERING ANALYSIS TOOLS FUNCTION

DEFAULT LOGICAL UNIT ASSIGNMENTS WITHIN ROBSIM

LU	USE
5	READ UNIT (TERMINAL)
6	WRITE UNIT (TERMINAL)
7	PRINTED OUTPUT UNIT
8-9	SIMULATION OUTPUT UNIT
10	SIMULATION OUTPUT FILE
11	ACTUATOR PARAMETERS INPUT FILE
14	LOAD OBJECTS DATA FILE
15	ERROR MESSAGE FILE
16	GAIN CONSTANTS FILE
17	TORQUE DATA INPUT FILE
18	ACC-VEL-THETA FILE
19	PROGRAMS OPTIONS FIE
20	PLOT DATA FILE
21	MOTION TIME HISTORY FILE
22	HARDWARE CONTROL SIGNALS
23	CONTROL MODULE OUTPUT FILE
24	CONTROL MODULE OUTPUT FILE

USER WILL BE PROMPTED FOR FILENAMES
TO ASSOCIATE WITH EACH LOGICAL UNIT
WHEN MARKED

ENTER RETURN TO CONTINUE

<CR>

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REQUIREMENTS ANALYSIS WITHOUT GRAPHICS
2	REQUIREMENTS ANALYSIS WITH GRAPHICS
3	RESPONSE SIMULATION WITHOUT GRAPHICS
4	RESPONSE SIMULATION WITH GRAPHICS
5	SET UP A MOTION PROGRAM
6	TERMINATE ANALYSIS TOOLS EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

1

ENTER FILENAME OF SYSTEM DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - DRD1:[ROBSIM]PLANDET.SYS

PLANAR.SYS

SYSTEM DATA FILE HAS BEEN READ
ALL COMMON BLOCKS ARE LOADED

DO YOU WISH TO MODIFY CURRENT OPTIONS?

- 1 LIST CURRENT OPTIONS
- 2 MODIFY CURRENT OPTIONS
- 3 RUN PROGRAM USING CURRENT OPTIONS

(911 FOR THE ROBSIM HELP LIBRARY)

2

DO YOU WISH PRINTED OUTPUT?

- 1 PRINT OUTPUT
- 2 PRINT CONDENSED OUTPUT
- 3 NO PRINTED OUTPUT

(911 FOR THE ROBSIM HELP LIBRARY)

2

ENTER FILENAME OF PRINTED OUTPUT FILE
TO BE CREATED. FILE MUST NOT CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - DRD0:[ROBSIM]PLANAR.PRT

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

REQEX.PRT

ENTER THE DESIRED TIME STEP FOR THE PRINTED OUTPUT

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

.05

DO YOU WISH TORQUE DATA OUTPUT?

- 1 TORQUE OUTPUT
- 2 NO TORQUE OUTPUT

(911 FOR THE ROBSIM HELP LIBRARY)

2

HOW DO YOU WISH TO CONTROL THE SIMULATION?
1 READ ACC-VEL-THETA DATA FILE
2 CONTROL WITH POLYNOMIAL TIME HISTORIES
3 CONTROL WITH E&S FUNCTION KEYS
(911 FOR THE ROBSIM HELP LIBRARY)

2

DO YOU WISH DYNAMICS COMPUTATIONS?
1 DO DYNAMICS COMPUTATIONS
2 NO DYNAMICS
(911 FOR THE ROBSIM HELP LIBRARY)

2

DO YOU WISH A SIMULATION OUTPUT FILE
1 WRITE SIMULATION FILE
2 NO SIMULATION FILE
(911 FOR THE ROBSIM HELP LIBRARY)

2

DO YOU WISH A PLOT DATA OUTPUT FILE?
1 SAVE A PLOT DATA FILE
2 NO PLOT DATA FILE
(911 FOR THE ROBSIM HELP LIBRARY)

1

ENTER FILENAME OF PLOT DATA OUTPUT FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CANNOT EXCEED 40.

EXAMPLE - DRDO:[ROBSIM]PLANAR. PLT

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

REQEX. PLT

ENTER PLOT DATA OUTPUT TIMESTEP

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

.05

ENTER PROGRAM START TIME (SEC)

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

0

ENTER PROGRAM STOP TIME (SEC)

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

2.

ENTER PROCESSING STEPSIZE (SEC)

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

.05

DO YOU WISH TO MODIFY CURRENT OPTIONS?

- 1 LIST OF CURRENT OPTIONS
- 2 MODIFY CURRENT OPTIONS
- 3 RUN PROGRAM USING CURRENT OPTIONS

(911 FOR THE ROBSIM HELP LIBRARY)

1

CURRENT OPTIONS INCLUDE:

PRINT CONDENSED OUTPUT TO REQEX.PRT
EVERY .50000E-01 SEC

PLOT DATA OUTPUT TO REQEX.PLT
EVERY .50000E-01 SEC

CURRENT SIMULATION TIMES ARE:

START TIME .00000E+00 SEC
STOP TIME 2.0000 SEC
TIME STEP .50000E-01 SEC

DO YOU WISH TO MODIFY CURRENT OPTIONS?

- 1 LIST CURRENT OPTIONS
- 2 MODIFY CURRENT OPTIONS
- 3 RUN PROGRAM USING CURRENT OPTIONS

(911 FOR THE ROBSIM HELP LIBRARY)

3

IN REQUIREMENTS ANALYSIS, TIME = 0.0000

ENTER THE FILENAME CONTAINING THE MOTION PROFILE FOR ARM 1
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CANNOT EXCEED 40
EXAMPLE - DRDO:[ROBSIM]MOPROF.THP

REQEX.THP

CHOOSE ONE OF THE FOLLOWING PLOT PACKAGES TO WRITE A FILE

1. THE BRIEF PACKAGE CONTAINING:

ENTRY 1 IS THE THETA VALUE
ENTRY 2 IS THE THETA DOT VALUE
ENTRY 3 IS THE THETA DOUBLE DOT VALUE
ENTRY 4 IS THE ACTUATOR TORQUE VALUE

ENTER INTEGER PLOT PACKAGE NUMBER TO CHOOSE A PACKAGE
OR ENTER RETURN TO CONTINUE

1

IN REQUIREMENTS ANALYSIS, TIME = 0.05000
IN REQUIREMENTS ANALYSIS, TIME = 0.10000
IN REQUIREMENTS ANALYSIS, TIME = 0.15000

o

o

o

IN REQUIREMENTS ANALYSIS, TIME = 2.00000

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REQUIREMENTS ANALYSIS WITHOUT GRAPHICS
2	REQUIREMENTS ANALYSIS WITH GRAPHICS
3	RESPONSE SIMULATION WITHOUT GRAPHICS
4	RESPONSE SIMULATION WITH GRAPHICS
5	SET UP A MOTION PROGRAM
6	TERMINATE ANALYSIS TOOLS EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

6

EXITING FROM ANALYSIS TOOLS FUNCTION
FORTRAN STOP
INPUT (Y) TO RUN SIMULATION ANALYSIS TOOLS FUNCTION AGAIN, (OTHERWISE, RETURN) <CR>
INPUT (Q) IF YOU WISH TO EXIT THE PROGRAM (OTHERWISE, RETURN)Q
\$

To plot the data saved during requirements analysis execution, refer to the instructions in the POSTDRVR section of the user's guide. To obtain the printed output from the example above, the user would type PRINT REQEX.PRT. A portion of the printed output from this run is shown.

ARM NUMBER 1 OF 1

NUMBER OF LINKS = 2

JOINT/LINKS	0	1	2	3

JOINT TYPE		1	1	
MASS (KILOGRAMS)	0.000E+00	5.11	1.70).000E+00
INITIAL JOINT POSITION (DEG. OR METERS)		0.000E+00	0.000E+00	
INITIAL JOINT VELOCITY (RAD/S OR METERS/SEC)		0.000E+00	0.000E+00	
MIN JOINT DISP.		-90.0	-120.	
MAX JOINT DISP.		90.0	120.	
MIN JOINT RATE		-1.50	-1.50	
MAX JOINT RATE		1.50	1.50	
CENTROID LOCATION (METERS)				
HCG(X)	0.000E+00	0.372	0.279	1.00
HCG(Y)	0.000E+00	0.000E+00	0.000E+00	0.000E+00
HCG(Z)	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LINK VECTOR (METERS)				
H12(X)	0.000E+00	0.200	0.426	0.348
H12(Y)	0.000E+00	0.000E+00	0.000E+00	0.000E+00
H12(Z)	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LINK NUMBER 0				
INERTIA MATRIX	0.00000E+00	0.00000E+00	0.00000E+00	
	0.00000E+00	0.00000E+00	0.00000E+00	
	0.00000E+00	0.00000E+00	0.00000E+00	
ORIENTATION MATRIX	0.00000	-1.00000	0.00000	
	1.00000	0.00000	0.00000	
	0.00000	0.00000	1.00000	

LINK NUMBER 1

INERTIA MATRIX	0.00000E+00	0.00000E+00	0.00000E+00
(KG-M**2)	0.00000E+00	0.52400E-01	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00

ORIENTATION MATRIX	0.00000	1.00000	0.00000
	-1.00000	0.00000	0.00000
	0.00000	0.00000	1.00000

LINK NUMBER 2

INERTIA MATRIX	0.00000E+00	0.00000E+00	0.00000E+00
(KG-M**2)	0.00000E+00	0.20200E-01	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00

ORIENTATION MATRIX	1.00000	0.00000	0.00000
	0.00000	1.00000	0.00000
	0.00000	0.00000	1.00000

LINK NUMBER 3

INERTIA MATRIX	0.00000E+00	0.00000E+00	0.00000E+00
(KG-M**2)	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00

ORIENTATION MATRIX	1.00000	0.00000	0.00000
	0.00000	1.00000	0.00000
	0.00000	0.00000	1.00000

ARM REACH = 2.0000

ACCELERATION DUE TO GRAVITY: 0.00000E+00 9.8070 0.00000E+00

CURRENT TIME 0.00000 ARM 1

JOINT	THETA	THETA-DOT	THETA-DOUBLE-DOT	ACT. TORQUE
1	0.0000	0.0000	-1.4137	0.0000
2	-30.0001	0.0000	0.9425	0.0000

CURRENT TIME 0.05000 ARM 1

JOINT	THETA	THETA-DOT	THETA-DOUBLE-DOT	ACT. TORQUE
1	-0.1013	0.0707	-1.4137	0.0000
2	-29.9326	0.0471	0.9425	0.0000

CURRENT TIME	0.10000	ARM 1		
JOINT	THETA	THETA-DOT	THETA-DOUBLE-DOT	ACT. TORQUE
1	-0.4050	0.1414	-1.4137	0.0000
2	-29.7301	0.0942	0.9425	0.0000
CURRENT TIME	0.15000	ARM 1		
JOINT	THETA	THETA-DOT	THETA-DOUBLE-DOT	ACT. TORQUE
1	-0.9113	0.2121	-1.4137	0.0000
2	-29.3926	0.1414	0.9425	0.0000
CURRENT TIME	0.20000	ARM 1		
JOINT	THETA	THETA-DOT	THETA-DOUBLE-DOT	ACT. TORQUE
1	-1.6200	0.2827	-1.4137	0.0000
2	-28.9201	0.1885	0.9425	0.0000
CURRENT TIME	0.25000	ARM 1		
JOINT	THETA	THETA-DOT	THETA-DOUBLE-DOT	ACT. TORQUE
1	-2.5313	0.3534	-1.4137	0.0000
2	-28.3126	0.2356	0.9425	0.0000
CURRENT TIME	0.30000	ARM 1		
JOINT	THETA	THETA-DOT	THETA-DOUBLE-DOT	ACT. TORQUE
1	-3.6450	0.4241	-1.4137	0.0000
2	-27.5701	0.2827	0.9425	0.0000
CURRENT TIME	0.35000	ARM 1		

Response Simulation

This subsection documents the use of the response simulation mode of the SIMDRVR portion of ROBSIM. Modes 3 and 4, simulation with and without graphics, are discussed in this subsection. The analyses carried out in both modes is that described in the analysis capability section of the main text. If the simulation with graphics is run, the motion of the manipulator system is displayed on the Evans and Sutherland picture system during execution. The current simulation time, joint positions (angles), and the percent of maximum allowable travel are also displayed.

Many of the prompts for the response simulation are similar to those for the requirements analysis. The first prompt is for the name of the system description file.

ENTER FILENAME OF SYSTEM DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - DRD1:[ROBSIM]PLNRARM.SYS

This file contains all the necessary information to describe the manipulator system and must have been defined previously using the INITDRV portion of ROBSIM. If this file is read in correctly, the following is displayed:

SYSTEM DATA FILE HAS BEEN READ
ALL COMMON BLOCKS ARE LOADED

Simulation run options. - Each time the response simulation is run, the flags defining options to be used are written to a file. On subsequent runs of the response simulation, the existing options file is read and the user may employ the previous options directly or input a new set of options:

DO YOU WISH TO MODIFY CURRENT OPTIONS?
1 LIST CURRENT OPTIONS
2 MODIFY CURRENT OPTIONS
3 RUN PROGRAM USING CURRENT OPTIONS
(911 FOR THE PRBSIM HELP LIBRARY)

(If no file exists, the user is automatically prompted for the individual option.)

Selecting option 1 in the above menu displays the current options in a list format as shown:

CURRENT OPTIONS INCLUDE:

PRINT CONDENSED OUTPUT TO ROBEX.PRT
EVERY 0.10000 SECONDS

SIMULATION IS TO BE CONTROLLED BY
INPUT TORQUES READ FROM ROBEX. TRQ
SAVE PLOT DATA IN ROBEX.PLT
EVERY 0.01000 SECONDS

CURRENT SIMULATION TIMES ARE:

START TIME = 0.00000 SECONDS
STOP TIME = 2.00000 SECONDS
TIME STEP = 0.01000 SECONDS

Option 2 prompts the user to input what run time options will be used. The first prompt is for the debug level. The user should input a 1 as this option is not currently implemented:

ENTER DESIRED DEBUG LEVEL (1-5)
(911 FOR THE ROBSIM HELP LIBRARY)

The next option is for printed output:

DO YOU WISH PRINTED OUTPUT?
1 PRINT OUTPUT
2 PRINT CONDENSED OUTPUT
3 NO PRINTED OUTPUT
(911 FOR THE ROBSIM HELP LIBRARY)

This will write run-time data to a formatted user-specified file that may later be printed out. The condensed output writes the following information for each joint:

- 1) Time;
- 2) Joint displacement;
- 3) Joint velocity;
- 4) Joint acceleration;
- 5) Actuator drive torque.

If the simulation is controlled using a PID controller, the following two parameters are also printed out:

- 6) Joint reference angular displacements;
- 7) motor amplifier input voltages.

When the full printout option is chosen, the following parameters are written in addition to those already listed:

- 8) Joint position vectors;
- 9) Joint velocity vector;
- 10) Linear acceleration vector;
- 11) Absolute angular velocities of the links;
- 12) Absolute angular accelerations of the links;
- 13) Local to world coordinate system transformation matrices;

- 14) Inertia matrices in world coordinates;
- 15) Joint force vector;
- 16) Joint/link centroid force vector;
- 17) Joint torque vector.

Entering a 1 or 2 for the printed output option causes the following prompts for filename and print interval to be displayed:

ENTER FILENAME OF PRINTED OUTPUT FILE
TO BE CREATED. FILE MUST NOT CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANAR.PRT

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

ENTER STPPRT - THE DESIRED TIMESTEP BETWEEN
PRINTED RESULTS

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

The next option prompt is for the method to be used to control the simulation:

ENTER A NUMBER FOR THE DESIRED TYPE OF CONTROL
1 READ INPUT TORQUE FILE
2 READ HARDWARE VOLTAGE FILE
3 USE PID CONTROL
(911 FOR THE ROBSIM HELP LIBRARY)

The input torque file (choice 1) is an unformatted file of torques applied at each joint as a function of time. This file can be generated during a requirements analysis run. The hardware voltage file (choice 2) is a listing of the voltage inputs to the dc torque motor amplifiers for each joint. This can be generated from an actual hardware arm, and then used as input to the simulation for hardware-software validation tasks. Both choice 1 and 2 require the user to input the data file name. PID control of the arm uses feedback compensation to drive the arm along a desired trajectory. The trajectory is established by executing the motion profile option described later. If force/torque or active compliance control is to be employed, PID control must be specified. These control options are described in the manipulator control section of the main text.

The program then prompts for the remaining output options:

DO YOU WISH AN ACC-VEL-THETA FILE?
1 SAVE AN ACC-VEL-THETA FILE
2 NO ACC-VEL-THETA FILE
(911 FOR THE ROBSIM HELP LIBRARY)

If this option is selected, the program writes an unformatted file of joint angular accelerations, velocities and displacements as functions of time. The user specifies a file name to save the data under and also the interval at which the data should be written. This data file may be subsequently used to drive a requirements analysis run.

Selecting the option for a simulation output file writes the joint displacements as functions of time in an unformatted file with user specified name:

```
DO YOU WISH A SIMULATION POSTPROCESSING OUTPUT FILE
  1  WRITE SIMULATION OUTPUT E&S FILE
  2  NO SIMULATION OUTPUT FILE
(911 FOR THE OBSIM HELP LIBRARY)
```

This file can then be used in the ROBSIM postprocessor to play back the motion that occurred during the simulation run.

The plot file option provides for saving data in an unformatted file, so that it can later be plotted on a graphics terminal or a hardcopy plotter using the ROBSIM postprocessing option:

```
DO YOU WANT A PLOT DATA OUTPUT FILE?
  1  SAVE A FILE OF PLOT DATA
  2  NO PLOT DATA FILE
(911 FOR THE ROBSIM HELP LIBRARY)
```

Seven different plot packages are available for use in a response simulation run. The choice of the plot package determines which variables are written to the file. The packages available are:

- 1) Brief - joint position,
 - joint velocity,
 - joint acceleration,
 - actuator drive torque;
- 2) End-effector - end effector x position,
 - end-effector y position,
 - end-effector z position,
 - end-effector x force,
 - end-effector y force,
 - end-effector z force,
 - end-effector x torque,
 - end-effector y torque,
 - end-effector z torque;
- 3) Joint positions - joint x position,
 - joint y position,
 - joint z position;

- 4) Reaction forces
 - joint force, x-direction,
 - joint force, y-direction,
 - joint force, z-direction,
 - joint torque, x-direction,
 - joint torque, y-direction,
 - joint torque, z-direction;
- 5) All of the above (1 thru 4)
- 6) PID control
 - amplifier voltage,
 - joint reference position,
 - joint position error,
 - end-effector reference x position,
 - end-effector reference y position,
 - end-effector reference z position,
 - error in end-effector x position,
 - error in end-effector y position,
 - error in end-effector z position,
 - error in end-effector rotational x position,
 - error in end-effector rotational y position,
 - error in end-effector rotational z position;
- 7) force/torque control
 - amplifier voltage,
 - x reference position,
 - y reference position,
 - z reference position,
 - reference force, x-direction,
 - reference force, y-direction,
 - reference force, z-direction,
 - reference torque, x-direction,
 - reference torque, y-direction,
 - reference torque, z-direction,
 - end-effector x position,
 - end-effector y position,
 - end-effector z position,
 - end-effector x force,
 - end-effector y force,
 - end-effector z force,
 - end-effector x torque,
 - end-effector y torque,
 - end-effector z torque,
 - end-effector x position error,
 - end-effector y position error,
 - end-effector z position error,
 - end-effector rotational x position error,
 - end-effector rotational y position error,
 - end-effector rotational z position error,
 - x direction force error,
 - y direction force error,
 - z direction force error,
 - x direction torque error,
 - y direction torque error,
 - z direction torque error.

If the user chooses to have a plot file written, only the file name and write interval are prompted at this time. The plot package desired is selected at a later time.

The last options defined in this group are the simulation start time, stop time and processing interval:

ENTER PROGRAM START TIME, IN SECONDS
(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

ENTER PROGRAM STOP TIME, IN SECONDS
(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

ENTER PROCESSING TIME STEPWISE, IN SECONDS
(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

The modification prompt will then be displayed and, if all the options were input correctly, the user should respond with the number 3:

DO YOU WISH TO MODIFY CURRENT OPTIONS?
1 LIST CURRENT OPTIONS
2 MODIFY CURRENT OPTIONS
3 RUN PROGRAM USING CURRENT OPTIONS
(911 FOR THE ROBSIM HELP LIBRARY)

For PID (or force/torque or active compliance) control of the system, the user must now input the names of the files containing the motion profiles for each arm of the system:

ENTER THE FILENAME CONTAINING THE MOTION PROFILE FOR ARM 1
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CANNOT EXCEED 40
EXAMPLE - DRD0:[ROBSIM]MOPROF.THP

For all methods of controlling the simulation, the user must define the initial positions and velocities for all joints of each arm:

DEFINE INITIAL CONDITIONS FOR ARM 1
ENTER INITIAL JOINT POSITIONS THETA, TH (DEG)
THETA FOR JOINT 1
THETA FOR JOINT 2
ENTER INITIAL JOINT VELOCITIES THETA DOT, (RAD/S)
THETA DOT FOR JOINT 1
THETA DOT FOR JOINT 2

The next prompt allows the user to include a constraint if desired. This could be used to simulate an immovable object or wall within the environment that the end-effector of an arm might come in contact with:

DO YOU WISH TO INCLUDE A CONSTRAINT?
1 INCLUDE CONSTRAINT
2 NO CONSTRAINT

If a 1 is input (inclusion of a constraint), the user is then prompted for the name of a file containing a description of this constraint. The file is formatted and set up by the user outside of the ROBSIM frame work using a system editor:

ENTER THE FILENAME FOR THE CONSTRAINT FILE:

If the system is controlled by the use of an input torque file or hardware voltage file, the gain constant prompts described below are not displayed.

For PID control, the next data to be input are gain constants for the control algorithms. Because the user may specify different types of control for different segments of the motion profile, the program prompts for data for each type of control separately. Before the actual gain values are requested, the user is asked if that specific type of control will be used during the current simulation run:

WILL YOU BE USING PID CONTROL DURING THIS RUN?
INPUT Y OR N

When a Y is input the following prompt is displayed, asking the user if the gain data will be read from a file or input from the terminal:

DO YOU WISH TO READ CONTROL GAINS FROM A FILE
OR INPUT THEM FROM THE TERMINAL
1 READ GAINS FROM FILE
2 INPUT FROM TERMINAL

If the control gains are not read from a file, the user must input the values from the terminal for each joint of each arm in the system:

ENTER THE PROPORTIONAL GAIN CONSTANT FOR
PID CONTROL OF JOINT 1 OF ARM 1
.02

ENTER THE DERIVATIVE GAIN CONSTANT FOR
PID CONTROL OF JOINT 1 OF ARM 1
0

ENTER THE INTEGRATING GAIN CONSTANT FOR
PID CONTROL OF JOINT 1 OF ARM 1
.05

ENTER THE PROPORTIONAL GAIN CONSTANT FOR
PID CONTROL OF JOINT 2 OF ARM 1
.02

ENTER THE DERIVATIVE GAIN CONSTANT FOR
PID CONTROL OF JOINT 2 OF ARM 1
0

ENTER THE INTEGRATING GAIN CONSTANT FOR
PID CONTROL OF JOINT 2 OF ARM 1
.05

If the control gains are to be read from a file, the name of this file is prompted for:

ENTER THE NAME OF FILE TO READ GAINS FROM

The file containing these gains should be a free-formatted file containing the responses, in order, to the prompts that would be issued for interactive input.

PID control is the first type of control for which the prompts are displayed. A similar set of prompts is displayed for force/torque control. The inputs required for active compliance control vary somewhat from those required for PID and force/torque control. Any end-effector bias forces are input here. The compliance control algorithm includes a lead-lag filter; the advance and delay time constants and proportional gain constant for that filter are defined here as well as the gain constants for the integrating and derivative control blocks.

After the gain data for the control algorithms have been entered, the user must input the control signal update interval.

ENTER THE CONTROL SIGNAL UPDATE INTERVAL

This determines how often the compensation calculations for controlling the manipulator system will be carried out. If the save plot file option was selected, the user is prompted for the manipulator motion data to be saved by designating an appropriate plot package:

CHOOSE ONE OF THE FOLLOWING PLOT PACKAGES TO WRITE TO A FILE

1. THE BRIEF PACKAGE CONTAINING:

ENTRY 1 IS THE THETA VALUE
ENTRY 2 IS THE THETA DOT VALUE
ENTRY 3 IS THE THETA DOUBLE DOT VALUE
ENTRY 4 IS THE DRIVE TORQUE VALUE

ENTER INTEGER PLOT PACKAGE NUMBER TO CHOOSE A PACKAGE
OR ENTER RETURN TO CONTINUE

2. THE END-EFFECTOR PACKAGE CONTAINING:

ENTRY 1 IS THE END EFF. X POSITION
ENTRY 2 IS THE END EFF. Y POSITION
ENTRY 3 IS THE END EFF. Z POSITION
ENTRY 4 IS THE END EFF. X FORCE
ENTRY 5 IS THE END EFF. Y FORCE
ENTRY 6 IS THE END EFF. Z FORCE
ENTRY 7 IS THE END EFF. X TORQUE
ENTRY 8 IS THE END EFF. Y TORQUE
ENTRY 9 IS THE END EFF. Z TORQUE

ENTER INTEGER PLOT PACKAGE NUMBER TO CHOOSE A PACKAGE
OR ENTER RETURN TO CONTINUE

3. THE JOINT POSITIONS PACKAGE CONTAINING:
ENTRY 1 IS THE JOINT X POSITION VALUE
ENTRY 2 IS THE JOINT Y POSITION VALUE
ENTRY 3 IS THE JOINT Z POSITION VALUE

ENTER INTEGER PLOT PACKAGE NUMBER TO CHOOSE A PACKAGE
OR ENTER RETURN TO CONTINUE

4. THE REACTION FORCES PACKAGE CONTAINING:
ENTRY 1 IS THE JOINT FORCE X VALUE
ENTRY 2 IS THE JOINT FORCE Y VALUE
ENTRY 3 IS THE JOINT FORCE Z VALUE
ENTRY 4 IS THE JOINT TORQUE X VALUE
ENTRY 5 IS THE JOINT TORQUE Y VALUE
ENTRY 6 IS THE JOINT TORQUE Z VALUE

ENTER INTEGER PLOT PACKAGE NUMBER TO CHOOSE A PACKAGE
OR ENTER RETURN TO CONTINUE

5. THE COMBINATION BRIEF/END-EFFECTOR/JOINT POSITIONS/REACTION FORCES
PACKAGE CONTAINING:
ENTRY 1 IS THE THETA VALUE
ENTRY 2 IS THE JOINT X POS. VALUE
ENTRY 3 IS THE JOINT Y POS. VALUE
ENTRY 4 IS THE JOINT Z POS. VALUE
ENTRY 5 IS THE THETA DOT VALUE
ENTRY 6 IS THE THETA DOUBLE DOT VALUE
ENTRY 7 IS THE JOINT X FORCE VALUE
ENTRY 8 IS THE JOINT Y FORCE VALUE
ENTRY 9 IS THE JOINT Z FORCE VALUE
ENTRY 10 IS THE JOINT X TORQUE VALUE
ENTRY 11 IS THE JOINT Y TORQUE VALUE
ENTRY 12 IS THE JOINT Z TORQUE VALUE
ENTRY 13 IS THE DRIVE TORQUE VALUE
ENTRY 14 IS THE END-EFF. X POSITION
ENTRY 15 IS THE END-EFF. Y POSITION
ENTRY 16 IS THE END-EFF. Z POSITION
ENTRY 17 IS THE END-EFF. X FORCE
ENTRY 18 IS THE END-EFF. Y FORCE
ENTRY 19 IS THE END-EFF. Z FORCE
ENTRY 20 IS THE END-EFF. X TORQUE
ENTRY 21 IS THE END-EFF. Y TORQUE
ENTRY 22 IS THE END-EFF. Z TORQUE

ENTER INTEGER PLOT PACKAGE NUMBER TO CHOOSE A PACKAGE
OR ENTER RETURN TO CONTINUE

6. THE PID CONTROL PACKAGE CONTAINING:

ENTRY 1 IS THE AMPLIFIER VALUE
ENTRY 2 IS THE JOINT REFERENCE ANGLE
ENTRY 3 IS THE JOINT POSITION ERROR
ENTRY 4 IS THE END-EFF. REF. X FORCE
ENTRY 5 IS THE END-EFF. REF. Y FORCE
ENTRY 6 IS THE END-EFF. REF. Z FORCE
ENTRY 7 IS THE END-EFF. X POS. FORCE
ENTRY 8 IS THE END-EFF. Y POS. FORCE
ENTRY 9 IS THE END-EFF. Z POS. FORCE
ENTRY 10 IS END-EFF. X ROT. POS. ERROR
ENTRY 11 IS END-EFF. Y ROT. POS. ERROR
ENTRY 12 IS END-EFF. Z ROT. POS. ERROR

ENTER INTEGER PLOT PACKAGE NUMBER TO CHOOSE A PACKAGE
OR ENTER RETURN TO CONTINUE

7. THE FORCE/TORQUE CONTROL PACKAGE CONTAINING:

ENTRY 1 IS THE AMPLIFIER VOLTAGE VALUE
ENTRY 2 IS THE REF. X POSITION VALUE
ENTRY 3 IS THE REF. Y POSITION VALUE
ENTRY 4 IS THE REF. Z POSITION VALUE
ENTRY 5 IS THE USER GIVEN REF. X FORCE
ENTRY 6 IS THE USER GIVEN REF. Y FORCE
ENTRY 7 IS THE USER GIVEN REF. Z FORCE
ENTRY 8 IS REF. FORCE ROT. VECT. X
ENTRY 9 IS REF. FORCE ROT. VECT. Y
ENTRY 10 IS REF. FORCE ROT. VECT. Z
ENTRY 11 IS THE END-EFF. X POSITION
ENTRY 12 IS THE END-EFF. Y POSITION
ENTRY 13 IS THE END-EFF. Z POSITION
ENTRY 14 IS THE END-EFF. X FORCE
ENTRY 15 IS THE END-EFF. Y FORCE
ENTRY 16 IS THE END-EFF. Z FORCE
ENTRY 17 IS THE END-EFF. X TORQUE
ENTRY 18 IS THE END-EFF. Y TORQUE
ENTRY 19 IS THE END-EFF. Z TORQUE
ENTRY 20 IS THE ERROR IN X POSITION
ENTRY 21 IS THE ERROR IN Y POSITION
ENTRY 22 IS THE ERROR IN Z POSITION
ENTRY 23 IS ERROR IN POS. X ROT. VALUE
ENTRY 24 IS ERROR IN POS. Y ROT. VALUE
ENTRY 25 IS ERROR IN POS. Z ROT. VALUE
ENTRY 26 IS THE ERROR IN X FORCE/TORQUE
ENTRY 27 IS THE ERROR IN Y FORCE/TORQUE
ENTRY 28 IS THE ERROR IN Z FORCE/TORQUE
ENTRY 29 IS ERROR IN X ROT. FORCE/TORQUE
ENTRY 30 IS ERROR IN Y ROT. FORCE/TORQUE
ENTRY 31 IS ERROR IN Z ROT. FORCE/TORQUE

SELECT PLOT PACKAGE DESIRED FOR SAVE

NUMBER	PACKAGE
1	BRIEF PACKAGE
2	END-EFFECTOR PACKAGE
3	JOINT POSITION PACKAGE
4	REACTION FORCES PACKAGE
5	COMBINATION OF ABOVE PACKAGES
6	PID CONTROL PACKAGE
7	FORCE/TORQUE CONTROL PACKAGE
8	TO WRITE DESCRIPTIONS AGAIN

ENTER INTEGER VALUE FOR MODE DESIRED

The choice of plot package defines which system variables are saved and written to the user-designated file.

This completes the input required for a response simulation run. As execution proceeds, the current simulation time is printed to the user's terminal to indicate progress. If the response simulation is run with graphics, the execution may be stopped at any time by pressing the first button on the Evans and Sutherland control panel. This allows the user to move or rotate the manipulator system display using E&S dials, to obtain different views. To resume program execution, the same button is again depressed.

Sample Run. Example A-9 illustrates the use of the ROBSIM response simulation capabilities without graphics. In this run the user commands a planar arm to move towards a wall and, using force/torque control, press against the wall with a force of 10 newtons. Desired outputs include a condensed printout, a simulation output file, and plots of joint positions as functions of time.

Example A-9

```
$ @ROBSIM
INPUT (INITDRVR)-- TO RUN ROBSIM SYSTEM DEFINITION FUNCTION
      (SIMDRVR)  -- TO RUN ROBSIM SIMULATION ANALYSIS TOOLS FUNCTION
      (POSTDRVR)-- TO RUN ROBSIM POST PROCESSOR FUNCTION
WHICH:SIMDRVR
Previous logical name assignment replaced
Previous logical name assignment replaced
```

ROBOTIC SYSTEM SIMULATION PROGRAM (ROBSIM)

ENTERING ANALYSIS TOOLS FUNCTION

DEFAULT LOGICAL UNIT ASSIGNMENTS USED WITHIN ROBSIM

LU	USE
5	READ UNIT (TERMINAL)
6	WRITE UNIT (TERMINAL)
7	PRINTED OUTPUT UNIT
8-9	SIMULATION INPUT FILE
10	SIMULATION OUTPUT FILE
11	ACTUATOR PARAMETERS INPUT FILE
14	LOAD OBJECTS DATA FILE
15	ERROR MESSAGE FILE
16	GAIN CONSTANTS FILE
17	TORQUE DATA INPUT FILE
18	ACC-VEL-THETA FILE
19	PROGRAMS OPTIONS FILE
20	PLOT DATA FILE
21	MOTION TIME HISTORY FILE
22	HARDWARE CONTROL SIGNALS
23	CONTROL OPTIONS INPUT FILE
24	CONTROL MODULE OUTPUT FILE

USER WILL BE PROMPTED FOR FILENAMES
TO ASSOCIATE WITH EACH LOGICAL UNIT
WHEN REQUIRED

ENTER RETURN TO CONTINUE

<CR>

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REQUIREMENTS ANALYSIS WITHOUT GRAPHICS
2	REQUIREMENTS ANALYSIS WITH GRAPHICS
3	RESPONSE SIMULATION WITHOUT GRAPHICS
4	RESPONSE SIMULATION WITH GRAPHICS
5	TERMINATE ANALYSIS TOOLS EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

3

ENTER FILENAME OF SYSTEM DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - DRD1:[ROBSIM]PLANDET.SYS
PLANAR.SYS

SYSTEM DATA FILE HAS BEEN READ
ALL COMMON BLOCKS ARE LOADED

DO YOU WISH TO MODIFY CURRENT OPTIONS?
1 LIST CURRENT OPTIONS
2 MODIFY CURRENT OPTIONS
3 RUN PROGRAM USING CURRENT OPTIONS
(911 FOR THE ROBSIM HELP LIBRARY)

2

ENTER DESIRED DEBUG LEVEL (1-5)
(911 FOR THE ROBSIM HELP LIBRARY)

1

DO YOU WISH PRINTED OUTPUT?
1 PRINT OUTPUT
2 PRINT CONDENSED OUTPUT
3 NO PRINTED OUTPUT
(911 FOR THE ROBSIM HELP LIBRARY)

2

ENTER FILENAME OF PRINTED OUTPUT FILE
TO BE CREATED. FILE MUST NOT CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - DRD0:[ROBSIM]PLANAR.PRT

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

RESPEX.PRT

ENTER STPPRT - THE DESIRED TIMESTEP BETWEEN
PRINTED RESULTS

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

.05

ENTER NUMBER FOR THE DESIRED TYPE OF CONTROL
1 READ INPUT TORQUE FILE
2 READ HARDWARE VOLTAGE FILE
3 USE PID CONTROL
(911 FOR THE ROBSIM HELP LIBRARY)

3

DO YOU WISH AN ACC-VEL-THETA FILE?

1 SAVE AN ACC-VEL-THETA FILE

2 NO ACC-VEL-THETA FILE

(911 FOR THE ROBSIM HELP LIBRARY)

2

DO YOU WISH A SIMULATION POSTPROCESSING OUTPUT FILE

1 WRITE SIMULATION OUTPUT E&S FILE

2 NO SIMULATION OUTPUT FILE

(911 FOR THE ROBSIM HELP LIBRARY)

1

ENTER FILENAME OF SIMULATION OUTPUT FILE
TO BE CREATED. FILE MUST NOT CURRENTLY EXIST.
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - DRDO:[ROBSIM]PLANAR.SOF

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

RESPEX.SOF

ENTER DESIRED STEP SIZE FOR SIMULATION OUTPUT

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

.005

DO YOU WANT A PLOT DATA OUTPUT FILE?

1 SAVE A FILE OR PLOT DATA

2 NO PLOT DATA FILE

(911 FOR THE ROBSIM HELP LIBRARY)

1

ENTER FILENAME OF PLOT DATA OUTPUT DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN THE FILENAME
CAN NOT EXCEED 40.
EXAMPLE - DRDO:[ROBSIM]PLANAR.PLT

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

RESPEX.PLT

ENTER STPLOT - THE DESIRED TIMESTEP FOR THE
PLOT DATA PRINTED OUTPUT

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

.005

ENTER PROGRAM START TIME, IN SECONDS

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

0

ENTER PROGRAM STOP TIME, IN SECONDS

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

3.

ENTER PROCESSING TIME STEPSIZE, IN SECONDS

(ENTER 911 FOR THE ROBSIM HELP LIBRARY)

.005

DO YOU WISH TO MODIFY THE CURRENT OPTIONS?

- 1 LIST CURRENT OPTIONS
- 2 MODIFY CURRENT OPTIONS
- 3 RUN PROGRAM USING CURRENT OPTIONS

(911 FOR THE ROBSIM HELP LIBRARY)

1

CURRENT OPTIONS INCLUDE

PRINT CONDENSED OUTPUT TO RESPEX. PRT
EVERY 0.05000 SECONDS

SIMULATION IS TO BE CONTROLLED BY
A PID CONTROLLER
SIMULATION POSTPROCESSING OUTPUT TO RESPEX.SOF
EVERY 0.00500 SECONDS

SAVE PLOT DATA IN RESPEX.PLT
EVERY 0.00500 SECONDS

DEBUG LEVEL = 1

CURRENT SIMULATION TIMES ARE:

START TIME = 0.00000 SECONDS
STOP TIME = 3.00000 SECONDS
TIME STEP = 0.00500 SECONDS

DO YOU WISH TO MODIFY CURRENT OPTIONS?

- 1 LIST CURRENT OPTIONS
- 2 MODIFY CURRENT OPTIONS
- 3 RUN PROGRAM USING CURRENT OPTIONS

(911 FOR THE ROBSIM HELP LIBRARY)

3

ENTER THE FILENAME CONTAINING THE MOTION PROFILE FOR ARM 1
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CANNOT EXCEED 40
EXAMPLE - DRDO:[ROBSIM]MOPROF.THP
RESPEX.THP

DEFINE INITIAL CONDITIONS FOR ARM 1

ENTER INITIAL JOINT POSITIONS THETA, TH (DEG)

0 THETA FOR JOINT 1
-30 THETA FOR JOINT 2

ENTER INITIAL JOINT VELOCITIES THETA DOT, (RAD/S)

0 THETA DOT FOR JOINT 1
0 THETA DOT FOR JOINT 2

DO YOU WISH TO INCLUDE A CONSTRAINT?

1 INCLUDE CONSTRAINT
2 NO CONSTRAINT
1

ENTER THE FILENAME FOR THE CONSTRAINT FILE: PLANE.CNS

WILL YOU BE USING PID CONTROL DURING THIS RUN?
INPUT Y OR N

N

WILL YOU BE USING FORCE/TORQUE CONTROL?
INPUT Y OR N

Y

DO YOU WISH TO READ CONTROL GAINS FROM A FILE
OR INPUT THEM FROM THE TERMINAL

1 READ GAINS FROM FILE
2 INPUT FROM TERNIMAL
2

ENTER THE PROPORTIONAL GAIN CONSTANT FOR
POSITION CONTROL OF JOINT 1 OF ARM 1
.02

ENTER THE DERIVATIVE GAIN CONSTANT FOR
POSITION CONTROL OF JOINT 1 OF ARM 1
0

ENTER THE INTEGRATING GAIN CONSTANT FOR
POSITION CONTROL OF JOINT 1 OF ARM 1
.05

ENTER THE PROPORTIONAL GAIN CONSTANT FOR
F/T CONTROL OF JOINT 1 OF ARM 1
.5

ENTER THE DERIVATIVE GAIN CONSTANT FOR
F/T CONTROL OF JOINT 1 OF ARM 1
0

ENTER THE INTEGRATING GAIN CONSTANT FOR
F/T CONTROL OF JOINT 1 OF ARM 1
10.

ENTER THE PROPORTIONAL GAIN CONSTANT FOR
POSITION CONTROL OF JOINT 2 OF ARM 1
.02

ENTER THE DERIVATIVE GAIN CONSTANT FOR
POSITION CONTROL OF JOINT 2 OF ARM 1
0

ENTER THE INTEGRATING GAIN CONSTANT FOR
POSITION CONTROL OF JOINT 2 OF ARM 1
.05

ENTER THE PROPORTIONAL GAIN CONSTANT FOR
F/T CONTROL OF JOINT 2 OF ARM 1
.5

ENTER THE DERIVATIVE GAIN CONSTANT FOR
F/T CONTROL OF JOINT 2 OF ARM 1
0

ENTER THE INTEGRATING GAIN CONSTANT FOR
F/T CONTROL OF JOINT 2 OF ARM 1
10.

WILL YOU BE USING COMPLIANCE CONTROL?
INPUT Y OR N
N

ENTER THE CONTROL SIGNAL UPDATE INTERVAL
.005

CHOOSE ONE OF THE FOLLOWING PLOT PACKAGES TO WRITE TO A FILE

1. THE BRIEF PACKAGE CONTAINING:
ENTRY 1 IS THE THETA VALUE
ENTRY 2 IS THE THETA DOT VALUE
ENTRY 3 IS THE THETA DOUBLE DOT VALUE
ENTRY 4 IS THE DRIVE TORQUE VALUE

ENTER INTEGER PLOT PACKAGE NUMBER TO CHOOSE A PACKAGE
OR ENTER RETURN TO CONTINUE

1

RESPONSE SIMULATION RUN, TIME = 0.00000
RESPONSE SIMULATION RUN, TIME = 0.00500
RESPONSE SIMULATION RUN, TIME = 0.01000
RESPONSE SIMULATION RUN, TIME = 0.01500
RESPONSE SIMULATION RUN, TIME = 0.02000
RESPONSE SIMULATION RUN, TIME = 0.02500

o

o

o

RESPONSE SIMULATION RUN, TIME = 3.00002

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REQUIREMENTS ANALYSIS WITHOUT GRAPHICS
2	REQUIREMENTS ANALYSIS WITH GRAPHICS
3	RESPONSE SIMULATION WITHOUT GRAPHICS
4	RESPONSE SIMULATION WITH GRAPHICS
5	SET UP A MOTION PROGRAM
6	TERMINATE ANALYSIS TOOLS EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

6

EXITING FROM ANALYSIS TOOLS FUNCTION
FORTRAN STOP
INPUT (Y) TO RUN SIMULATION ANALYSIS TOOLS FUNCTION AGAIN, (OTHERWISE, RETURN) <CR>
INPUT (Q) IF YOU WISH TO EXIT THE PROGRAM (OTHERWISE, RETURN)Q

To plot the data saved or to play back the simulation file, refer to the POSTDRVR section of this user's guide. To obtain the printout, the user should type PRINT RESPEX.PRT. A portion of this printout is shown.

ARM NUMBER 1 OF 1

NUMBER OF LINKS = 2

JOINT/LINKS	0	1	2	3
JOINT TYPE		1	1	
MASS (KILOGRAMS)	0.000E+00	5.11	1.70	0.000E+00
INITIAL JOINT POSITION (DEG. OR METERS)		0.000E+00	0.000E+00	
INITIAL JOINT VELOCITY (RAD/S OR METERS/SEC)		0.000E+00	0.000E+00	
MIN JOINT DISP.		-90.0	-120.	
MAX JOINT DISP.		90.0	120.	
MIN JOINT RATE		-1.50	-1.50	
MAX JOINT RATE		1.50	1.50	
CENTROID LOCATION (METERS)				
HCG(X)	0.000E+00	0.372	0.279	1.00
HCG(Y)	0.000E+00	0.000E+00	0.000E+00	0.000E+00
HCG(Z)	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LINK VECTOR (METERS)				
H12(X)	0.000E+00	0.200	0.426	0.348
H12(Y)	0.000E+00	0.000E+00	0.000E+00	0.000E+00
H12(Z)	0.000E+00	0.000E+00	0.000E+00	0.000E+00
LINK NUMBER	0			
INERTIA MATRIX				
	0.00000E+00	0.00000E+00	0.00000E+00	
	0.00000E+00	0.00000E+00	0.00000E+00	
	0.00000E+00	0.00000E+00	0.00000E+00	
ORIENTATION MATRIX				
	0.00000	-1.00000	0.00000	
	1.00000	0.00000	0.00000	
	0.00000	0.00000	1.00000	

LINK NUMBER 1

INERTIA MATRIX	0.00000E+00	0.00000E+00	0.00000E+00
(KG-M**2)	0.00000E+00	0.52400E-01	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00
ORIENTATION MATRIX	0.00000	1.00000	0.00000
	-1.00000	0.00000	0.00000
	0.00000	0.00000	1.00000

LINK NUMBER 2

INERTIA MATRIX	0.00000E+00	0.00000E+00	0.00000E+00
(KG-M**2)	0.00000E+00	0.20200E-01	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00
ORIENTATION MATRIX	1.00000	0.00000	0.00000
	0.00000	1.00000	0.00000
	0.00000	0.00000	1.00000

LINK NUMBER 3

INERTIA MATRIX	0.00000E+00	0.00000E+00	0.00000E+00
(KG-M**2)	0.00000E+00	0.00000E+00	0.00000E+00
	0.00000E+00	0.00000E+00	0.00000E+00
ORIENTATION MATRIX	1.00000	0.00000	0.00000
	0.00000	1.00000	0.00000
	0.00000	0.00000	1.00000

ARM REACH = 2.0000

ACCELERATION DUE TO GRAVITY: 0.00000E+00 9.8070 0.00000E+00

Motion Profiles

This subsection describes how the motion of a manipulator arm is specified. The user is presented with various menus detailing the available options and with input prompts to define these options. The complete motion is broken down into segments, where each segment contains a description of a distinct move or other type of task-oriented command. Once a segment is defined, it is written to a user-named file and another segment is defined until the complete manipulator motion is specified. If the system contains multiple arms, a complete motion profile is described for each arm separately.

To use this SIMDRVR option, the user must first input the name of the file containing data describing the manipulator system (defined in the INITDRVR portion of ROBSIM):

```
ENTER FILE NAME OF SYSTEM DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - DRD1:[ROBSIM]PLNARM.SYS
```

This gives the program the geometry information needed when prompting the user for input data. Next, the following prompt is displayed:

DEFINING TASK PROGRAM FOR ARM 1

DO YOU WISH TO MODIFY A FILE OF
EXISTING TIME HISTORIES?

- 1 MODIFY TIME HISTORIES FROM A FILE
- 2 INPUT TIME HISTORIES FROM USER TERMINAL
- 3 MAKE A PRINT COPY OF A TIME HISTORY FILE

If a 1 is entered, the user is prompted for the name of the file containing the motion profile data to be modified and a file name under which to save the modified data:

```
ENTER THE FILENAME OF TIME HISTORY DATA FOR ARM 1
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - DRD0:[ROBSIM]PLNARM.THP
```

ENTER THE FILENAME FOR STORING THE TASK PROGRAM
FOR ARM 1

Choice 2 just asks the user for the file name under which to save the motion profile data. Choice 3 will write the motion profile data from a user-specified file to a formatted file for printing. This choice then terminates the motion program mode and the user is returned to the main SIMDRVR menu. An example of a motion profile listing is shown:

TIME HISTORY PROFILE: FTEX.PRT

BELOW ARE LISTED THE INITIAL JOINT DISPLACEMENTS
FOR ALL JOINTS OF ARM 1

THIS DATA IS REQUIRED FOR ALL CONTROL MODES

JOINT 1 0.0000
JOINT 2 -30.000

CURRENT PROGRAM STEP IS:

USE FORCE/TORQUE CONTROL WITH
THE FOLLOWING PARAMETERS

FORCE UNIT VECTOR 0.0000 0.0000 1.0000
FORCE MAGNITUDE -10.00

CURRENT PROGRAM STEP IS:

DURATION = 0.500 SEC

POSITION CONTROL OF END-EFFECTOR MOTION;
X, Y, Z TRANSLATION AND ROTATION AT THE
END OF THE TIME SEGMENT ARE:

0.727 0.200 0.210 0.000 -25.000 0.000

FINAL ORIENTATION MATRIX IS:

0.90631 0.00000 -0.42262
0.00000 1.00000 0.00000
0.42262 0.00000 0.90631

The user is now prompted for the initial joint angles:

ENTER THE INITIAL ANGLES FOR ARM 1
(DEGREES OR METERS)

ENTER THETA FOR JOINT 1

ENTER THETA FOR JOINT 2

ENTER 1 TO CONTINUE

ENTER 2 TO MODIFY INITIAL ANGLES

If a motion file is being modified, the current values are displayed and the user is given the choice of using the current values or modifying them:

BELOW ARE LISTED THE INITIAL JOINT DISPLACEMENTS
FOR ALL JOINTS OF ARM 1

THIS DATA IS REQUIRED FOR ALL CONTROL MODES

JOINT 1 0.0000
JOINT 2 -30.0001

DO YOU WISH TO

- 1 MODIFY INITIAL JOINT DISPLACEMENTS
- 2 USE CURRENT ANGLES

Once the initial displacements are established, the following description is displayed.

CONTROL DATA INPUT FOR ARM 1

RATE MOTION IS CONTROLLED BY USER INPUT POLYNOMIAL FUNCTIONS OF TIME. INPUT IS FOR THE COEFFICIENTS, STARTING WITH THE COEFFICIENT FOR THE HIGHEST ORDER TERM FIRST AND ENDING WITH THE COEFFICIENT FOR THE ZERO ORDER TERM.

POSITION IS CONTROLLED BY USER INPUT OF THE END POSITION OF THE END EFFECTOR OR EACH JOINT
A DURATION TIME, IN SECONDS, IS INPUT WITH EACH SET OF COEFFICIENTS TO PROVIDE A TIME SEGMENT OVER WHICH THE COEFFICIENTS ARE VALID.

ENTER RETURN TO CONTINUE

The program now prompts the user for segment data, one segment at a time. If an existing file is being modified, a description of the current segment is displayed along with modification menu as shown here:

CURRENT PROGRAM STEP IS:

DURATION = 0.400 SEC

POSITION CONTROL OF END-EFFECTOR MOTION:
X,Y,Z TRANSLATION AND ROTATION AT THE
END OF THE TIME SEGMENT ARE:

0.727 0.200 0.210 0.000 -25.000 0.000

FINAL ORIENTATION MATRIX IS:

0.86603	0.00000	-0.50000
0.00000	1.00000	0.00000
0.50000	0.00000	0.86603

DO YOU WISH TO MODIFY THIS STEP?

- 1 NO MODIFICATION
- 2 REDEFINE CURRENT STEP
- 3 DELETE CURRENT STEP
- 4 INSERT NEW STEP AHEAD OF
CURRENT STEP

ENTER INTEGER

If no modification is desired, the program reads the next task step and repeats this prompt. To redefine the current step, it is deleted and the interactive step definition procedure executes to replace the step. Alternatively, the current step can be deleted and the program proceeds to the next task step in the file. Finally, a new task step can be inserted prior to the current step, after which the modification prompt is repeated (thereby allowing multiple insertions).

The remainder of the motion profile discussion will be handled as new input although the same procedures apply for profile modification. Options for each task segment fall into two categories as shown by the following prompt:

IS CURRENT STEP A MOTION?

1 MOTION SEGMENT

2 NO-MOTION STEP (E.G., GRAPH, WAIT, ETC)

ENTER INTEGER

Motion control specifications. - This corresponds to choice 1 in the preceding menu and allows the user to define where or how the manipulator arm will move. The user may control the motion of the end-effector or of each manipulator joint. Independent of which part of the manipulator is to be controlled, the user may also decide if the control variable is to be rate or position. The four motion control options are:

- 1) Joint rate control;
- 2) End-effector rate control;
- 3) Joint position control;
- 4) End-effector position control.

The first step in defining a motion is to specify the length of time the motion will take.

SPECIFY DURATION TIME, (SEC), FOR SEGMENT

The user then defines if end-effector or joint motion is to be controlled, and if the control variable is rate or position.

ENTER 1 FOR CONTROL OF INDIVIDUAL JOINTS

ENTER 2 FOR CONTROL OF END EFFECTOR MOTION

ENTER 1 FOR RATE CONTROL

ENTER 2 FOR POSITION CONTROL

If joint rate control is requested, the user must input the coefficients of an nth-order polynomial function of time for each joint of the arm. This polynomial equation defines the rate at which the angle of a given joint changes. Cubic polynomials are currently implemented, requiring four coefficients:

FOR RATE CONTROL, COEFFICIENTS MUST PRODUCE
TRANSLATIONAL RATES IN METERS/SEC AND
ROTATIONAL RATES IN RADIANS PER SECOND

FOR INDIVIDUAL JOINT CONTROL, THE CONTROL
FUNCTIONS SPECIFY MOTION OF EACH JOINT ABOUT
THE SINGLE DEGREE OF FREEDOM OF THAT JOINT

SPECIFY COEFFICIENTS FOR MOTION (RADIAN/SEC)
OF JOINT 1 ABOUT THE JOINT SINGLE DEGREE
OF FREEDOM

ENTER 4 REAL*4 NUMBERS SEPARATED BY COMMAS

SPECIFY COEFFICIENTS FOR MOTION (RADIAN/SEC)
OF JOINT 2 ABOUT THE JOINT SINGLE DEGREE
OF FREEDOM

ENTER 4 REAL*4 NUMBERS SEPARATED BY COMMAS

End effector rate control also requires the user to input coefficients of a polynomial functions of time. This case, however, requires six sets of coefficients for each arm in the system--three for x, y, and z translational rates and three for x, y, and z rotational rates of the end effector. The user may define these coefficients to define polynomials in either the end-effector or world coordinate system:

FOR RATE CONTROL, COEFFICIENTS MUST PRODUCE
TRANSLATIONAL RATES IN METERS/SEC AND
ROTATIONAL RATES IN RADIAN PER SECOND

ENTER 1 TO INPUT RATE IN BASE COORDINATES
ENTER 2 TO INPUT RATE IN END-EFFECTOR COORDINATES

SPECIFY COEFFICIENTS FOR TRANSLATIONAL MOTION
ALONG THE X-AXIS (RATES IN METERS/SEC)

ENTER 4 REAL*4 NUMBERS SEPARATED BY COMMAS

SPECIFY COEFFICIENTS FOR TRANSLATIONAL MOTION
ALONG THE Y-AXIS (RATES IN METERS/SEC)

ENTER 4 REAL*4 NUMBERS SEPARATED BY COMMAS

SPECIFY COEFFICIENTS FOR TRANSLATIONAL MOTION
ALONG THE Z-AXIS (RATES IN METERS/SEC)

ENTER 4 REAL*4 NUMBERS SEPARATED BY COMMAS

SPECIFY COEFFICIENTS FOR ROTATIONAL MOTION
ABOUT THE X-AXIS (RATES IN RADIAN PER SEC)

ENTER 4 REAL*4 NUMBERS SEPARATED BY COMMAS

SPECIFY COEFFICIENTS FOR ROTATIONAL MOTION
ABOUT THE Y-AXIS (RATES IN RADIAN PER SEC)

ENTER 4 REAL*4 NUMBERS SEPARATED BY COMMAS

SPECIFY COEFFICIENTS FOR ROTATIONAL MOTION
ABOUT THE Z-AXIS (RATES IN RADIAN PER SEC)

ENTER 4 REAL*4 NUMBERS SEPARATED BY COMMAS

For position control, only the position of the arm at the end of the motion segment is defined. Joint position control requires that the user input the relative displacement of each joint at the end of the segment. Remember that the time allowed for this move has also been defined so the end position specified should not cause the manipulator rate limits to be exceeded:

FOR POSITION CONTROL, INPUTS MUST BE
TRANSLATIONS IN METERS AND ROTATIONS IN DEGREES

FOR INDIVIDUAL JOINT CONTROL, THE CONTROL
FUNCTIONS SPECIFY MOTION OF EACH JOINT ABOUT
THE SINGLE DEGREE OF FREEDOM OF THAT JOINT

SPECIFY THE JOINT POSITION (DEGREES) FOR JOINT 1
AT THE END OF THE TIME SEGMENT

SPECIFY THE JOINT POSITION (DEGREES) FOR JOINT 2
AT THE END OF THE TIME SEGMENT

For end effector position control, the user inputs an x, y, and z position in the world coordinate system, for the end-effector reference point. The final orientation of the end-effector coordinate system with respect to the world coordinate system is also specified by defining successive rotation angles about the world x-, y-, and z-axes that rotate the end-effector from an initial reference position aligned with the world system to the desired final orientation:

FOR POSITION CONTROL, INPUTS MUST BE
TRANSLATIONS IN METERS AND ROTATIONS IN DEGREES

FOR END EFFECTORS POSITION CONTROL, INPUTS
MUST BE IN WORLD COORDINATE SYSTEM

SPECIFY X,Y,Z COORDINATES (METERS) OF THE END EFFECTOR
POSITION AT END OF TIME SEGMENT IN WORLD COOR
ENTER 3 REAL*4 NUMBERS SEPARATED BY COMMAS

SPECIFY THE ORIENTATION OF THE END EFFECTOR AT
THE END OF THE TIME SEGMENT USING ANGLES OF
ROTATION (DEGREES) ABOUT THE X, THEN Y, THEN Z AXES
ENTER 3 REAL*4 NUMBERS SEPARATED BY COMMAS

The above describes the user options available for motion-type specifications. The analysis capability section of the main text describes the arm motions generated from these specifications.

Nonmotion control specifications. - The other set of options available for controlling the arm is classified as nonmotion options. Those currently available within ROBSIM are shown in the menu displayed when the no-motion segment option is chosen:

WHICH ACTION DO YOU WISH?

- 1 GRASP OBJECT
- 2 RELEASE OBJECT
- 3 CHANGE TOOL REFERENCE POINT
- 4 WAIT STATE, TIME DELAY
- 5 TURN FORCE/TORQUE CONTROL ON OR OFF
- 6 TURN ACTIVE COMPLIANCE CONTROL ON OR OFF

ENTER INTEGER

The grasp command (1) allows the user to specify that the motion of a load object be linked to that of an arm. An example would be to move the end-effector of the manipulator arm to the handle of a tool, grasp the tool, and then use the tool to perform a task on a workpiece. When the grasp command is chosen, the following prompt is displayed:

WHICH OBJECT? (ENTER OBJECT NUMBER)

The user must input a number corresponding to the load object to be grasped. The load objects must be included in the system during system definition. The subsequent motion of the load is displayed graphically with the arm motion. Use of this command also causes the mass properties (mass, center of gravity, and inertia) of the load object to be combined with those of the end effector to insure proper modeling of the arm response. The new effective mass properties of the end effector are used until the object is released.

The release command (2) uncouples the load object and arm motions and restores the end effector mass properties to the values they had before the load object was grasped. The user inputs the number corresponding to the load object the arm is to release. The object will then remain in the position occupied when the command was given, even if it is in midair.

The change tool reference point command (3) allows the user to input a new location for this point. The reference point is a point fixed in the tool coordinate system whose motion is controlled when end effector rate or position control is used. Its location in the end effector coordinate system is specified and if no reference point is specified, it is set to the origin of the end-effector coordinate system by default:

ENTER X,Y,Z LOCATION OF NEW TOOL REFERENCE
POINT IN LOCAL TOOL COORDINATES. (IN METERS)

This command could be used after a tool has been picked up by the end effector and the end of the tool is to be directed to perform a given task.

The wait on time delay command (4) allows the motion of the manipulator arm to be stopped for a length of time specified by the user:

ENTER TIME DELAY FOR WAIT STATE

This command is implemented internally by using rate control of the manipulator joints and setting all of the coefficients of the rate polynomial to zero.

The force/torque and compliance control commands (5 and 6) set flags to specify that these types of control be used during response simulation. When force/torque control is flagged, the user must also input the control forces and torques. This is done by defining up to three force components and up to three torque components to control. For each component, the user must input a unit vector describing the direction in world coordinates of the force or torque to be controlled and the desired magnitude of this force or torque. As described in the main text, feedback compensation is used to obtain reaction forces on the end effector equal to the prescribed force. Constraints on the end effector motion must generally be specified for this control mode. Control block gains are defined during execution of response simulation. The prompts for this command are shown:

ENTER THE NUMBER DENOTING FORCE/TORQUE CONTROL ON OR OFF

0 FORCE/TORQUE CONTROL OFF

1 USE FORCE/TORQUE CONTROL

(NOTE: FORCE/TORQUE CONTROL CAN BE USED ONLY
WITH PID CONTROL OF END EFFECTOR POSITION

1

ENTER THE NUMBER OF FORCE COMPONENTS YOU
WISH TO CONTROL (0 TO 3 DIRECTIONS ALLOWED)

1

ALL FORCE VECTORS MUST BE ORTHOGONAL AND
SPECIFIED IN WORLD COORDINATES

ENTER THE UNIT FORCE VECTOR FOR DIRECTION 1

1,0,0

ENTER THE MAGNITUDE OF THIS VECTOR

10

ENTER THE NUMBER OF TORQUE COMPONENTS YOU
WISH TO CONTROL (0 TO 3 DIRECTIONS ALLOWED)

When active compliance control is requested, the user must specify a compliance or stiffness matrix for the end effector reference position:

ENTER THE NUMBER DENOTING ACTIVE COMPLIANCE
CONTROL ON OR OFF

0 COMPLIANCE CONTROL OFF

1 USE ACTIVE COMPLIANCE CONTROL

(NOTE: TO USE THIS, PID CONTROL MUST BE SPECIFIED
IN THE PROGRAM OPTIONS SECTION

1

ENTER THE STIFFNESS MATRIX FOR THE END
EFFECTOR REFERENCE POINT TO CONTROL
(ENTER ONE ROW OF THE MATRIX AT A TIME)

ENTER ROW 1 OF THE STIFFNESS MATRIX
10,0,0,0,0,0

ENTER ROW 2 OF THE STIFFNESS MATRIX
0,10,0,0,0,0

ENTER ROW 3 OF THE STIFFNESS MATRIX
0,0,10,0,0,0

ENTER ROW 4 OF THE STIFFNESS MATRIX
0,0,0,10,0,0

ENTER ROW 5 OF THE STIFFNESS MATRIX
0,0,0,0,10,0

ENTER ROW 6 OF THE STIFFNESS MATRIX
0,0,0,0,0,10

This main text discusses how this 6x6 stiffness matrix is used to couple the control of the end-effector position and force. Gain constants used for this control are defined during execution of response simulation.

This concludes the description of nonmotion options. After each segment (motion or nonmotion) is entered, the user is given a chance to redefine the data just entered in the event a mistake was made during input:

DID YOU SCREW UP?
ENTER 1 TO STORE THIS STEP
ENTER 2 TO REDEFINE THIS STEP

If the response is 1, the segment data are written to the file selected by the user at the start of the motion profile definition.

Sample run. Example A-10 shows the use of this mode (motion profile) of the SIMDRVR portion of ROBSIM to set up a profile for the following task.

A robot arm, doing an assembly task is required to pick a small part up off a table and then place it against another epoxy-covered part for 2 seconds with a force of 10 newtons and then return to its home position. The segments needed to define this motion are listed:

- 1) Move to small part on table;
- 2) Grasp part;
- 3) Move small part to epoxy-covered part;
- 4) Press against part until force = 10 newtons;

- 5) Hold 2 seconds;
- 6) Release;
- 7) Return to home position.

Example A-10

```
@ROBSIM
INPUT (INITDRVR)---TO RUN ROBSIM SYSTEM DEFINITION FUNCTION
      (SIMDRVR)  ---TO RUN ROBSIM SIMULATION ANALYSIS TOOLS FUNCTION
      (POSTDRVR)---TO RUN ROBSIM POST PROCESSOR FUNCTION
WHICH:SIMDRVR
Previous logical name assignment replaced
Previous logical name assignment replaced
```

ROBOTIC SYSTEM SIMULATION PROGRAM (ROBSIM)

ENTERING ANALYSIS TOOLS FUNCTION

DEFAULT LOGICAL UNIT ASSIGNMENTS WITHIN ROBSIM

LU	USE
5	READ UNIT (TERMINAL)
6	WRITE UNIT (TERMINAL)
7	PRINTED OUTPUT UNIT
8-9	SIMULATION OUTPUT UNIT
10	SIMULATION OUTPUT FILE
11	ACTUATOR PARAMETERS INPUT FILE
14	LOAD OBJECTS DATA FILE
15	ERROR MESSAGE FILE
16	GAIN CONSTANTS FILE
17	TORQUE DATA INPUT FILE
18	ACC-VEL-THETA FILE
19	PROGRAMS OPTIONS FIE
20	PLOT DATA FILE
21	MOTION TIME HISTORY FILE
22	HARDWARE CONTROL SIGNALS
23	CONTROL MODULE OUTPUT FILE
24	CONTROL MODULE OUTPUT FILE

USER WILL BE PROMPTED FOR FILENAMES
TO ASSOCIATE WITH EACH LOGICAL UNIT
WHEN MARKED

ENTER RETURN TO CONTINUE

<CR>

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REQUIREMENTS ANALYSIS WITHOUT GRAPHICS
2	REQUIREMENTS ANALYSIS WITH GRAPHICS
3	RESPONSE SIMULATION WITHOUT GRAPHICS
4	RESPONSE SIMULATION WITH GRAPHICS
5	SET UP A MOTION PROGRAM
6	TERMINATE ANALYSIS TOOLS EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

5

ENTER FILENAME OF SYSTEM DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - DRD1:[ROBSIM]PLANDET.SYS
PLANAR.SYS

SYSTEM DATA FILE HAS BEEN READ
ALL COMMON BLOCKS ARE LOADED

DEFINING TASK PROGRAM FOR ARM 1

DO YOU WISH TO MODIFY A FILE OF
EXISTING TIME HISTORIES?

- 1 MODIFY TIME HISTORIES FROM A FILE
- 2 INPUT TIME HISTORIES FROM USER TERMINAL
- 3 MAKE A PRINT COPY OF A TIME HISTORY FILE

2

ENTER THE FILENAME FOR STORING THE TASK PROGRAM
FOR ARM 1

MOPROF.THP

ENTER THE INITIAL ANGLES FOR ARM 1
(DEGREES OR METERS)
ENTER THETA FOR JOINT !

0

ENTER THETA FOR JOINT 2

-30

ENTER 1 TO CONTINUE
ENTER 2 TO MODIFY INITIAL ANGLES

1

CONTROL DATA INPUT FOR ARM 1

RATE MOTION IS CONTROLLED BY USER INPUT POLYNOMIAL
FUNCTIONS OF TIME. INPUT IS FOR THE COEFFICIENTS,
STARTING WITH THE COEFFICIENT FOR THE HIGHEST ORDER
TERM FIRST AND ENDING WITH THE COEFFICIENT FOR THE
ZERO ORDER TERM.

POSITION IS CONTROLLED BY USER INPUT OF THE END
POSITION OF THE END EFFECTOR EACH JOINT
A DURATION TIME, IN SECONDS, IS INPUT WITH EACH SET
OF COEFFICIENTS TO PROVIDE A TIME SEGMENT OVER
WHICH THE COEFFICIENTS ARE VALID.

ENTER RETURN TO CONTINUE

<CR>

IS CURRENT STEP A MOTION?

1 MOTION SEGMENT

2 NO-MOTION STEP (E.G., GRASP, WAIT, ETC)

ENTER INTEGER

1

SPECIFY DURATION TIME, (SEC), FOR SEGMENT

.5

ENTER 1 FOR CONTROL OF INDIVIDUAL JOINTS

ENTER 2 FOR CONTROL OF END EFFECTOR MOTION

2

ENTER 1 FOR RATE CONTROL

ENTER 2 FOR POSITION CONTROL

2

FOR POSITION CONTROL, INPUTS MUST BE
TRANSLATIONS IN METERS AND ROTATIONS IN DEGREES

FOR END EFFECTOR POSITION CONTROL, INPUTS
MUST BE IN WORLD COORDINATE SYSTEM

SPECIFY X,Y,Z COORDINATES (METERS) OF THE END EFFECTOR
POSITION AT END OF TIME SEGMENT IN WORLD COOR
ENTER 3 REAL*4 NUMBERS SEPARATED BY COMMAS

.4,.2,.5

SPECIFY THE ORIENTATION OF THE END EFFECTOR AT
THE END OF THE TIME SEGMENT USING ANGLES OF
ROTATION (DEGREES) ABOUT THE X, THEN Y, THEN Z AXES
ENTER 3 REAL*4 NUMBERS SEPARATED BY COMMAS

0,-30,0

DID YOU SCREW UP?

ENTER 1 TO STORE THIS STEP

ENTER 2 TO REDEFINE THIS STEP

1

DO YOU WISH MORE PROGRAM STEPS?

ENTER 1 TO INPUT ANOTHER PROGRAM STEP

ENTER 2 TO TERMINATE PROGRAM SEQUENCE

1

IS CURRENT STEP A MOTION?

- 1 MOTION SEGMENT
- 2 NO-MOTION STEP (E.G., GRASP, WAIT, ETC)

ENTER INTEGER

2

WHICH ACTION DO YOU WISH?

- 1 GRASP OBJECT
- 2 RELEASE OBJECT
- 3 CHANGE TOOL REFERENCE POINT
- 4 WAIT STATE, TIME DELAY
- 5 TURN FORCE/TORQUE CONTROL ON OR OFF
- 6 TURN ACTIVE COMPLIANCE CONTROL ON OR OFF

ENTER INTEGER

1

WHICH OBJECT? (ENTER OBJECT NUMBER)

2

DID YOU SCREW UP?

- ENTER 1 TO STORE THIS STEP
- ENTER 2 TO REDEFINE THIS STEP

1

DO YOU WISH MORE PROGRAM STEPS?

- ENTER 1 TO INPUT ANOTHER PROGRAM STEP
- ENTER 2 TO TERMINATE PROGRAM SEQUENCE

1

IS CURRENT STEP A MOTION?

- 1 MOTION SEGMENT
- 2 NO-MOTION STEP (E.G., GRASP, WAIT, ETC)

ENTER INTEGER

1

SPECIFY DURATION TIME, (SEC), FOR SEGMENT

.5

- ENTER 1 FOR CONTROL OF INDIVIDUAL JOINTS
- ENTER 2 FOR CONTROL OF END EFFECTOR MOTION

2

- ENTER 1 FOR RATE CONTROL
- ENTER 2 FOR POSITION CONTROL

2

FOR POSITION CONTROL, INPUTS MUST BE
TRANSLATIONS IN METERS AND ROTATIONS IN DEGREES

FOR END EFFECTOR POSITION CONTROL, INPUTS
MUST BE IN WORLD COORDINATE SYSTEM

SPECIFY X,Y,Z COORDINATES (METERS) OF THE END EFFECTOR
POSITION AT END OF TIME SEGMENT IN WORLD COOR
ENTER 3 REAL*4 NUMBERS SEPARATED BY COMMAS

.4,.2,1.0

SPECIFY THE ORIENTATION OF THE END EFFECTOR AT
THE END OF THE TIME SEGMENT USING ANGLES OF
ROTATION (DEGREES) ABOUT THE X, THEN Y, THEN Z AXES
ENTER 3 REAL*4 NUMBERS SEPARATED BY COMAS

0,-25,0

DID YOU SCREW UP?

ENTER 1 TO STORE THIS STEP

ENTER 2 TO REDEFINE THIS STEP

1

DO YOU WISH MORE PROGRAM STEPS?

ENTER 1 TO INPUT ANOTHER PROGRAM STEP

ENTER 2 TO TERMINATE PROGRAM SEQUENCE

1

IS CURRENT STEP A MOTION?

1 MOTION SEGMENT

2 NO-MOTION STEP (E.G., GRASP, WAIT, ETC)

ENTER INTEGER

2

WHICH ACTION DO YOU WISH?

1 GRASP OBJECT

2 RELEASE OBJECT

3 CHANGE TOOL REFERENCE POINT

4 WAIT STATE, TIME DELAY

5 TURN FORCE/TORQUE CONTROL ON OR OFF

6 TURN ACTIVE COMPLIANCE CONTROL ON OR OFF

ENTER INTEGER

5

ENTER THE NUMBER DENOTING FORCE/TORQUE CONTROL ON OR OFF

0 FORCE/TORQUE CONTROLL OFF

1 USE FORCE/TORQUE CONTROL

(NOTE: FORCE/TORQUE CONTROL CAN BE USED ONLY
WITH PID CONTROL OF END EFFECTOR POSITION)

1

ENTER THE NUMBER OF FORCE COMPONENTS YOU
WISH TO CONTROL (0 TO 3 DIRECTIONS ALLOWED)

1

ALL FORCE VECTORS MUST BE ORTHOGONAL AND
SPECIFIED IN WORLD COORDINATES

ENTER THE UNIT FORCE VECTOR FOR DIRECTION 1
0,0,-1

ENTER THE MAGNITUDE OF THIS VECTOR
10

ENTER THE NUMBER OF TORQUE COMPONENTS YOU
WISH TO CONTROL (0 TO 3 DIRECTIONS ALLOWED)
0

DID YOU SCREW UP?
ENTER 1 TO STORE THIS STEP
ENTER 2 TO REDEFINE THIS STEP
1

DO YOU WISH MORE PROGRAM STEPS?
ENTER 1 TO INPUT ANOTHER PROGRAM STEP
ENTER 2 TO TERMINATE PROGRAM SEQUENCE
1

IS CURRENT STEP A MOTION?
1 MOTION SEGMENT
2 NO-MOTION STEP (E.G., GRASP, WAIT, ETC)
ENTER INTEGER
1

SPECIFY DURATION TIME, (SEC), FOR SEGMENT
.5

ENTER 1 FOR CONTROL OF INDIVIDUAL JOINTS
ENTER 2 FOR CONTROL OF END EFFECTOR MOTION
2

ENTER 1 FOR RATE CONTROL
ENTER 2 FOR POSITION CONTROL
2

FOR POSITION CONTROL, INPUTS MUST BE
TRANSLATIONS IN METERS AND ROTATIONS IN DEGREES

FOR END EFFECTOR POSITION CONTROL, INPUTS
MUST BE IN WORLD COORDINATE SYSTEM

SPECIFY X,Y,Z COORDINATES (METERS) OF THE END EFFECTOR
POSITION AT END OF TIME SEGMENT IN WORLD COOR
ENTER 3 REAL*4 NUMBERS SEPARATED BY COMMAS
.4,.2,1.1

SPECIFY THE ORIENTATION OF THE END EFFECTOR AT
THE END OF THE TIME SEGMENT USING ANGLES OF
ROTATION (DEGREES) ABOUT THE X, THEN Y, THEN Z AXES
ENTER 3 REAL*4 NUMBERS SEPARATED BY COMAS
0,-25,0

DID YOU SCREW UP?

ENTER 1 TO STORE THIS STEP

ENTER 2 TO REDEFINE THIS STEP

1

DO YOU WISH MORE PROGRAM STEPS?

ENTER 1 TO INPUT ANOTHER PROGRAM STEP

ENTER 2 TO TERMINATE PROGRAM SEQUENCE

1

IS CURRENT STEP A MOTION?

1 MOTION SEGMENT

2 NO-MOTION STEP (E.G., GRASP, WAIT, ETC)

ENTER INTEGER

2

WHICH ACTION DO YOU WISH?

1 GRASP OBJECT

2 RELEASE OBJECT

3 CHANGE TOOL REFERENCE POINT

4 WAIT STATE, TIME DELAY

5 TURN FORCE/TORQUE CONTROL ON OR OFF

6 TURN ACTIVE COMPLIANCE CONTROL ON OR OFF

ENTER INTEGER

4

ENTER TIME DELAY FOR WAIT STATE

2.

DID YOU SCREW UP?

ENTER 1 TO STORE THIS STEP

ENTER 2 TO REDEFINE THIS STEP

1

DO YOU WISH MORE PROGRAM STEPS?

ENTER 1 TO INPUT ANOTHER PROGRAM STEP

ENTER 2 TO TERMINATE PROGRAM SEQUENCE

1

IS CURRENT STEP A MOTION?

1 MOTION SEGMENT

2 NO-MOTION STEP (E.G., GRASP, WAIT, ETC)

ENTER INTEGER

2

WHICH ACTION DO YOU WISH?

1 GRASP OBJECT

2 RELEASE OBJECT

3 CHANGE TOOL REFERENCE POINT

4 WAIT STATE, TIME DELAY

5 TURN FORCE/TORQUE CONTROL ON OR OFF

6 TURN ACTIVE COMPLIANCE CONTROL ON OR OFF

ENTER INTEGER

5

ENTER THE NUMBER DENOTING FORCE/TORQUE CONTROL ON OR OFF
0 FORCE/TORQUE CONTROL OFF
1 USE FORCE/TORQUE CONTROL
(NOTE: FORCE/TORQUE CONTROL CAN BE USED ONLY
WITH PID CONTROL OF END EFFECTOR POSITION)
0

DID YOU SCREW UP?
ENTER 1 TO STORE THIS STEP
ENTER 2 TO REDEFINE THIS STEP
1

DO YOU WISH MORE PROGRAM STEPS?
ENTER 1 TO INPUT ANOTHER PROGRAM STEP
ENTER 2 TO TERMINATE PROGRAM SEQUENCE
1

IS CURRENT STEP A MOTION?
1 MOTION SEGMENT
2 NO-MOTION STEP (E.G., GRASP, WAIT, ETC)
ENTER INTEGER
2

WHICH ACTION DO YOU WISH?
1 GRASP OBJECT
2 RELEASE OBJECT
3 CHANGE TOOL REFERENCE POINT
4 WAIT STATE, TIME DELAY
5 TURN FORCE/TORQUE CONTROL ON OR OFF
6 TURN ACTIVE COMPLIANCE CONTROL ON OR OFF
ENTER INTEGER
2
WHICH OBJECT? (ENTER OBJECT NUMBER)
2

DID YOU SCREW UP?
ENTER 1 TO STORE THIS STEP
ENTER 2 TO REDEFINE THIS STEP
1

DO YOU WISH MORE PROGRAM STEPS?
ENTER 1 TO INPUT ANOTHER PROGRAM STEP
ENTER 2 TO TERMINATE PROGRAM SEQUENCE
1

IS CURRENT STEP A MOTION?
1 MOTION SEGMENT
2 NO-MOTION STEP (E.G., GRASP, WAIT, ETC)
ENTER INTEGER
1

1. SPECIFY DURATION TIME, (SEC), FOR SEGMENT

ENTER 1 FOR CONTROL OF INDIVIDUAL JOINTS
ENTER 2 FOR CONTROL OF END EFFECTOR MOTION

1

ENTER 1 FOR RATE CONTROL
ENTER 2 FOR POSITION CONTROL

2

FOR POSITION CONTROL, INPUTS MUST BE
TRANSLATIONS IN METERS AND ROTATIONS IN DEGREES

FOR INDIVIDUAL JOINT CONTROL, THE CONTROL
FUNCTIONS SPECIFY MOTION OF EACH JOINT ABOUT
THE SINGLE DEGREE OF FREEDOM OF THAT JOINT

SPECIFY THE JOINT POSITION (DEGREES) FOR JOINT 1
AT THE END OF THE TIME SEGMENT

0

SPECIFY THE JOINT POSITION (DEGREES) FOR JOINT 2
AT THE END OF THE TIME SEGMENT

0

DID YOU SCREW UP?

ENTER 1 TO STORE THIS STEP
ENTER 2 TO REDEFINE THIS STEP

1

DO YOU WISH MORE PROGRAM STEPS?

ENTER 1 TO INPUT ANOTHER PROGRAM STEP
ENTER 2 TO TERMINATE PROGRAM SEQUENCE

2

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REQUIREMENTS ANALYSIS WITHOUT GRAPHICS
2	REQUIREMENTS ANALYSIS WITH GRAPHICS
3	RESPONSE SIMULATION WITHOUT GRAPHICS
4	RESPONSE SIMULATION WITH GRAPHICS
5	SET UP A MOTION PROGRAM
6	TERMINATE ANALYSIS TOOLS EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

6

EXITING FROM ANALYSIS TOOLS FUNCTION
FORTRAN STOP

INPUT (Y) TO RUN SIMULATION ANALYSIS TOOLS FUNCTION AGAIN, (OTHERWISE, RETURN)
INPUT (Q) IF YOU WISH TO EXIT THE PROGRAM (OTHERWISE, RETURN)Q

The profile established in Example A-10 completely defines the motion of a manipulator arm. If the system contains multiple arms, the motion profile for each arm must be defined. After the motion profiles of all of the arms in the system have been defined, the user may run any of the other modes of the SIMDRVR section of ROBSIM using these profiles.

THE POSTPROCESSOR USER'S GUIDE

This portion of the user's guide describes the use of the postprocessor function of ROBSIM that allows the replay of a robotic system motion output file ('.SOF') that was written during a previous analysis tools simulation execution, permits comparison of the output simulation motion with a real hardware execution motion output file, and contains an x-y plotting capability for the parameter values written during an earlier robotic simulation run (saved in the '.PLT' file names). The philosophy of this ROBSIM function is to provide useful utilities for analyzing the results obtained during execution of the analysis tools function, either the requirements or the response simulation implementations.

The ROBSIM postprocessor uses the Evans and Sutherland multipicture system to provide all graphics replay of hardware and simulation motion. The E&S displays the movements of the robotic arms and loads within the environment as they originally occurred. A robotic system geometry ('.SYS') file must also exist to perform an E&S simulation replay. The system plot capacity incorporates the VMS DI3000 x-y plot package for parameter vs parameter plotting on a Hewlett-Packard plotter or a VAX VT125 graphics terminal.

This driver operates in an interactive mode, prompting the user for the postprocessing option desired. Valid options are:

- 1) Replay robotic system simulation motion only;
- 2) Replay simulation versus hardware motion;
- 3) Parameter versus parameter plots;
- 4) Terminate postprocessor program execution.

Additional postprocessing capabilities may be added to the postprocessor function program as desired.

After entry into the postprocessor, the program requires a mode response. The question will be to choose one of the three subprocesses mentioned above or to end this processor function. The user input parameter is as specified:

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REPLAY GRAPHIC SIMULATION MOTION ONLY
2	REPLAY GRAPHIC SIMULATION VERSUS HARDWARE MOTION
3	PARAMETER VERSUS PARAMETER PLOTS
4	TERMINATE POST PROCESSOR EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

In the postprocessor executive, the result of executing option 1 is to provide a replay of the robotic system joint motions produced from a simulation run and show the robot tasks performed. Option 2 provides a comparison of the resultant motion from direct hardware theta values read and the corresponding simulation motion, including programmed robot commands executed. If option 3 is selected, a procedure begins that provides parameter versus parameter plots of any of the data computed and written to one of the seven possible plot file packages during the requirements or simulation analysis tools function. Option 4 returns execution to the ROBSIM command file level.

At this point the discussion is separated into sections based on the menu options previously listed. Mode 1 is discussed in the section entitled Simulation Motion Replay Procedure; this explains the procedure of user interaction required to display the faster postsimulation motion on the E&S. The mode 2 option is discussed in the section Simulation vs Hardware Motion Replay Procedure; it includes information on how to form a ROBSIM software interface with a real hardware system to show the difference in the output joint angle values, where the hardware theta results represent the theoretical simulation goals. The user option, mode 3, is covered under the heading Parameter versus Parameter Plot Package Procedure; it covers the mandatory user inputs for plotting values of internal program parameters that were written to a user-specified time-tagged file during a previous simulation process.

Simulation Motion Replay Procedure

This section documents the use of the postprocessor function that provides a replay of the robotic system motion produced during a previous run of the requirements or simulation phase of the analysis tools function. It opens the chosen robotic system geometry ('.SYS') and simulation output ('.SOF') files for replay, and displays the motions with E&S line graphics. The simulation output data file is read for each time step to load the joint displacements, and the graphics called with the displacements at each time step, to update the system motion display.

The user is prompted for the name of the file containing the robotic system geometry created during the system definition function, and for the file name of the corresponding simulation output file generated during the analysis tools function execution.

The user input for the geometry file should be entered when the following is encountered:

```
ENTER FILENAME OF SYSTEM DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANDET.SYS
```

and the simulation output file to be replayed should be given for:

SYSTEM DATA FILE HAS BEEN READ
ALL COMMON BLOCKS ARE LOADED

ENTER FILENAME OF SIMULATION OUTPUT FILE
WHICH CORRESPONDS TO THE REQUESTED
SIMULATION INPUT FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANSIM.SOF

The unformatted data file containing the contents of pertinent stored parameter data is read into the COMMON blocks within the program, initially to re-define the system as it appeared at creation. The system graphics object arrays are read from the total robotic system geometry file saved during the system initialization process. The motion graphics capability in the postprocessor simulation replay function is similar to that of the simulation/requirements analysis tools function; the pending motion displays the environment, load and robotic system movements within the environment. The advantage of replay of the requirements or simulation graphics is a quicker display of the motion that occurred in the prior analysis processor run.

For the graphics, the robotic arms are initialized and displayed in the start time conditions. The display is scaled through use of the stored COMMON variable, system span, that was chosen while creating the robotic system scenario during the system definition function. As an initial prod, the user signifies dynamic motion commencement by depressing the RETURN key:

ENTER RETURN TO BEGIN MOTION

For each successive time step the display is updated to the current processing time step condition. The joint translational position vectors and absolute orientation matrices in the inertial system are loaded internally in the program. The form of the graphics picture output is bordered on the right with columns showing the current processing time joint angles (degrees) in column 1 and the percent of the maximum displacement permissible that is presently traversed for each joint of each arm, in column 2. The current simulation processing time is accrued at the top of the display, and the run title and Martin Marietta logo printed. In the postprocessing graphics, it is to be noted that during motion of the system, the environment and arm bases displayed are constant and therefore not updated.

The user will be allowed the use of an Evans and Sutherland extended function key reserved for cessation of system playback motion. While extended switch number 0 is activated, simulation playback is halted and the user is allowed the freedom to change the translational, rotational and zoom perspectives of the displayed picture through movement of the Evans and Sutherland extended analog dials. When analysis in this manner is complete, depressing the same function key number 0 resumes playback motion and simulation time continues updating. A light indicator in the function key is used to inform the user of the key status; when lighted, the perspective viewing is in operation.

Load object grasp and release commands are preprogrammed and read from the simulation output file. Such actions are designated for performance at a particular simulation time step (SDF), and are affiliated with a particular load object in the system scenario. The SOF includes a load flag to signify the grasp or release time-tagged events.

During grasping an object, the program adds the load mass properties to that of the arm end-effector to simulate a load object assumed at the robot tool. This procedure first checks to see that the arm is not already holding a load object or that another arm is not holding the desired load object. If these conditions are satisfied, the vector from the tool origin to the load center of gravity (in the tool coordinate system) is calculated, as well as the inertia matrix of the load in the tool coordinate system. The load mass properties are combined with those of the tool, and stored in tool variables. Here it is assumed that the arm is in a position that would enable it to grasp the load object, and that the load object will not slip after being held and moved by the arm. It is also assumed that the tool is centered about the object being grasped so no adjustments need to be made while the arm is grasping the load object.

The arm simulates releasing a load object by resetting the tool mass properties and updating the load object location and orientation. It checks if the arm is holding an object that it can release. If this is the case, the tool mass properties (mass, center of gravity, and inertia matrix) are reset to the values they were assigned before picking up the load object, and the load location and orientation are calculated for the place the load was set down. It is assumed that the object will stay where released.

When the motion is complete, the graphics display is terminated with:

ENTER RETURN TO TERMINATE GRAPHICS AND CONTINUE

At completion of motion replay, the user is asked whether a hardcopy printout meta-file should be written for regeneration on the Hewlett-Packard x-y plotter. If it is wished to create a paper copy of the final graphics display, the user should input a file name prefix for the answer to the hardcopy question, otherwise RETURN. The file prefix will be appended with '.PIC' and saved in the user directory. For instructions on exercising the meta-file output routine, see the user's guide introduction.

Sample run. - A sample interactive run of the replay option follows. Figures A-32 through A-34 were taken during this postprocessing playback.

Example A-11

@ROBSIM
INPUT (INITDRVR)-- TO RUN ROBSIM SYSTEM DEFINITION FUNCTION
 (SIMDRVR) -- TO RUN ROBSIM SIMULATION ANALYSIS TOOLS FUNCTION
 (POSTDRVR)-- TO RUN ROBSIM POST PROCESSOR FUNCTION
WHICH:POSTDRVR
DO YOU WISH (1) TERMINAL OR (2) HARDCOPY PLOTTING?
ENTER INTEGER:2
Previous logical name assignment replaced
Previous logical name assignment replaced

ROBOTIC SYSTEM SIMULATION PROGRAM (ROBSIM)

ENTERING POST PROCESSING FUNCTION

DEFAULT LOGICAL UNIT ASSIGNMENTS USED WITHIN ROBSIM

LU	USE
5	READ UNIT (TERMINAL)
6	WRITE UNIT (TERMINAL)
7	PRINTED OUTPUT UNIT
8-9	SIMULATION INPUT FILE
10	SIMULATION OUTPUT FILE
11	ACTUATOR PARAMETERS INPUT FILE
14	LOAD OBJECTS DATA FILE
15	ERROR MESSAGE FILE
16	GAIN CONSTANTS FILE
17	TORQUE DATA INPUT FILE
18	ACC-VEL-THETA FILE
19	PROGRAMS OPTIONS FILE
20	PLOT DATA FILE
21	MOTION TIME HISTORY FILE
22	HARDWARE CONTROL SIGNALS
23	CONTROL OPTIONS INPUT FILE
24	CONTROL MODULE OUTPUT FILE

USER WILL BE PROMPTED FOR FILENAMES
TO ASSOCIATE WITH EACH LOGICAL UNIT
WHEN REQUIRED

ENTER RETURN TO CONTINUE

<CR>

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REPLAY GRAPHIC SIMULATION MOTION ONLY
2	REPLAY GRAPHIC SIMULATION VERSUS HARDWARE MOTION
3	PARAMETER VERSUS PARAMETER PLOTS
4	TERMINATE POST PROCESSOR EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

1

ENTER FILENAME OF SYSTEM DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANDET.SYS
PLNDET.SYS

SYSTEM DATA FILE HAS BEEN READ
ALL COMMON BLOCKS ARE LOADED

ENTER FILENAME OF SIMULATION OUTPUT FILE
WHICH CORRESPONDS TO THE REQUESTED
SIMULATION INPUT FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANSIM.SOF
PLANAR.SOF

ENTER RETURN TO BEGIN MOTION

<CR>

ENTER RETURN TO TERMINATE GRAPHICS AND CONTINUE

<CR>

*** HARD COPY ***
ENTER ".PIC" FILE NAME PREFIX
(CR|=NONE) :PLNDET1
FILE "PLNDET1.PIC" OPENED

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REPLAY GRAPHIC SIMULATION MOTION ONLY
2	REPLAY GRAPHIC SIMULATION VERSUS HARDWARE MOTION
3	PARAMETER VERSUS PARAMETER PLOTS
4	TERMINATE POST PROCESSOR EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

4

EXITING FROM POST PROCESSING FUNCTION

ORIGINAL PAGE IS
OF POOR QUALITY

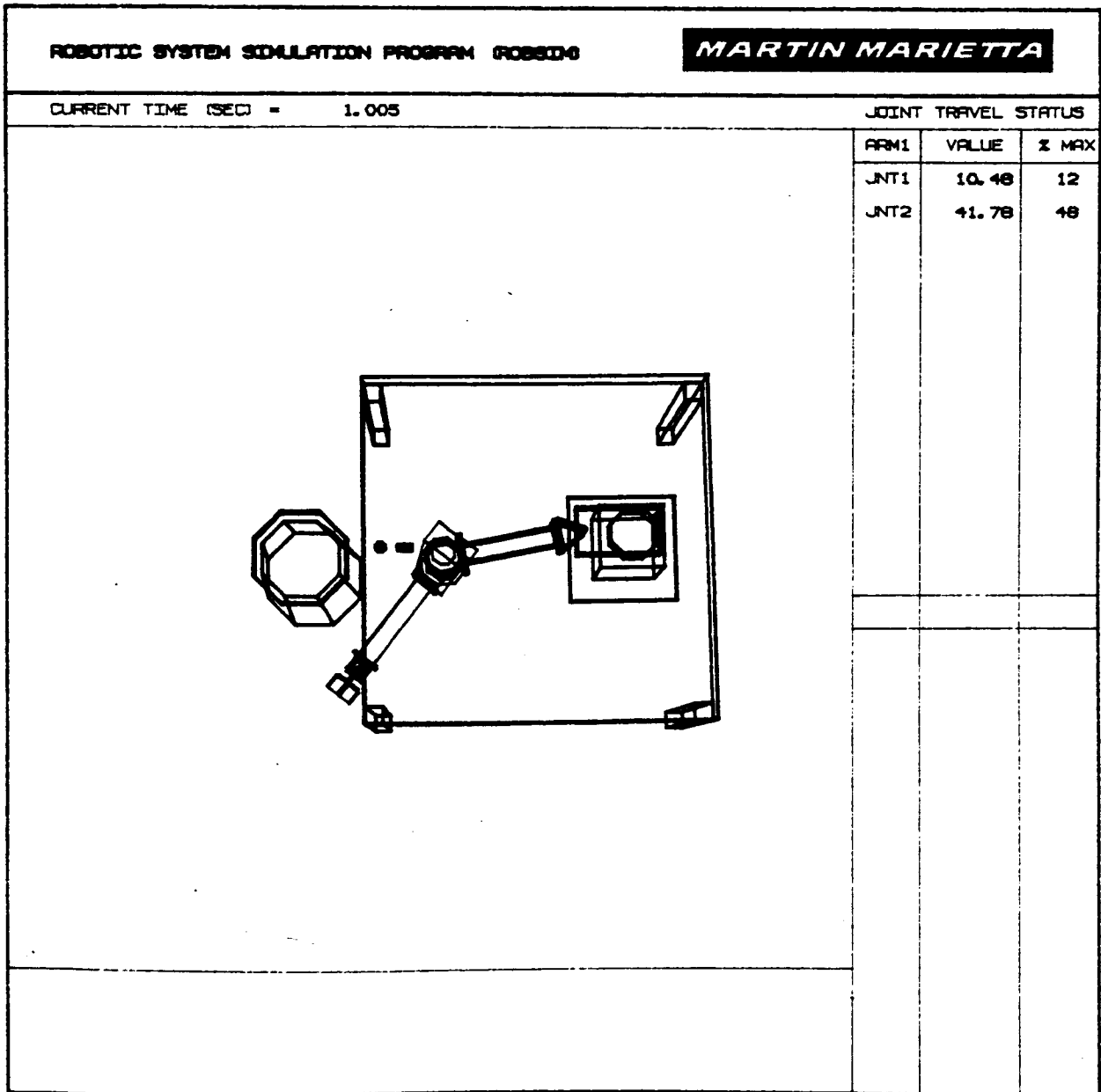


Figure A-32. - Postprocessor motion replay display at $t = 1$ second.

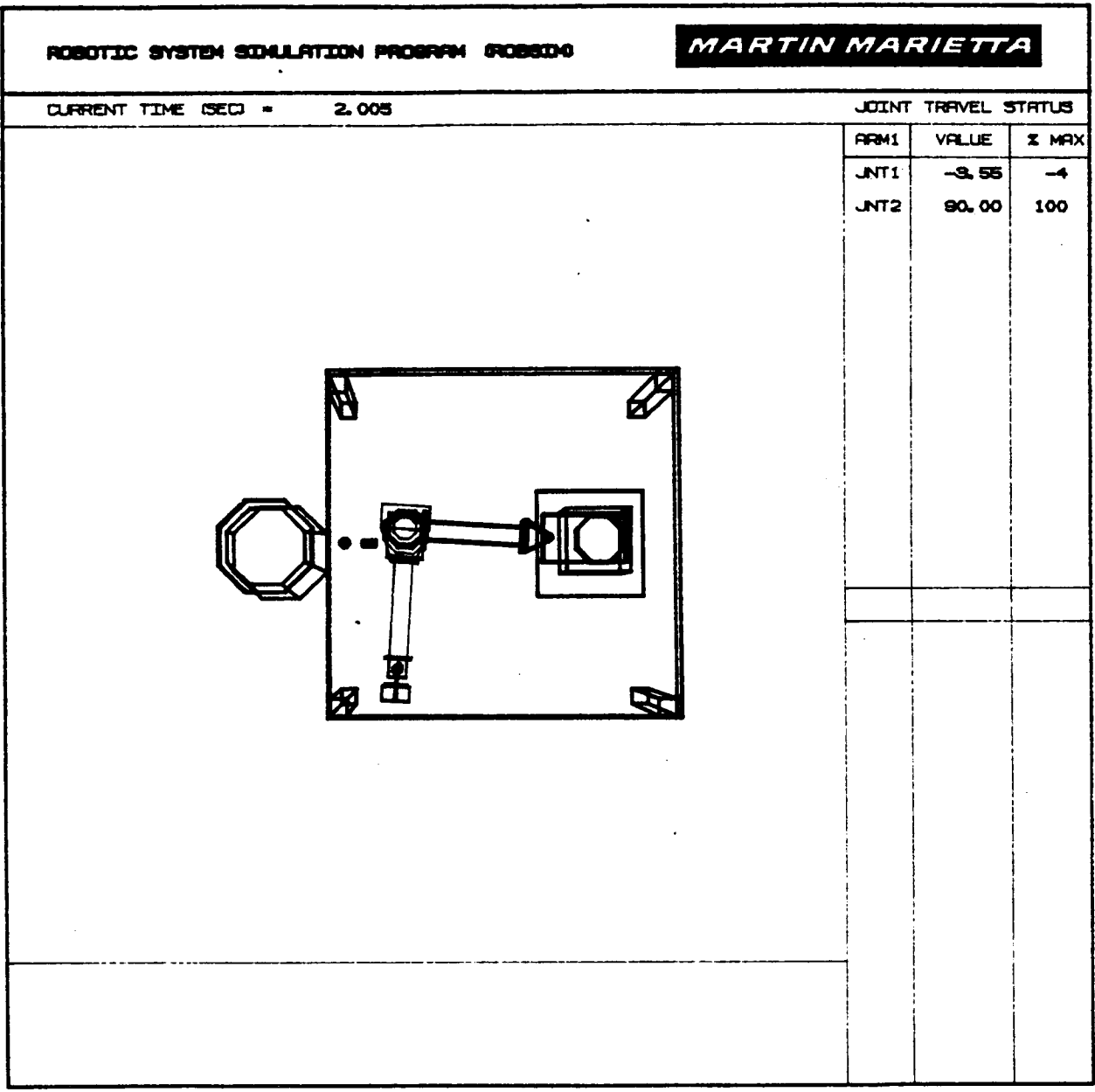


Figure A-33. - Postprocessor motion replay display at t = 2 second.

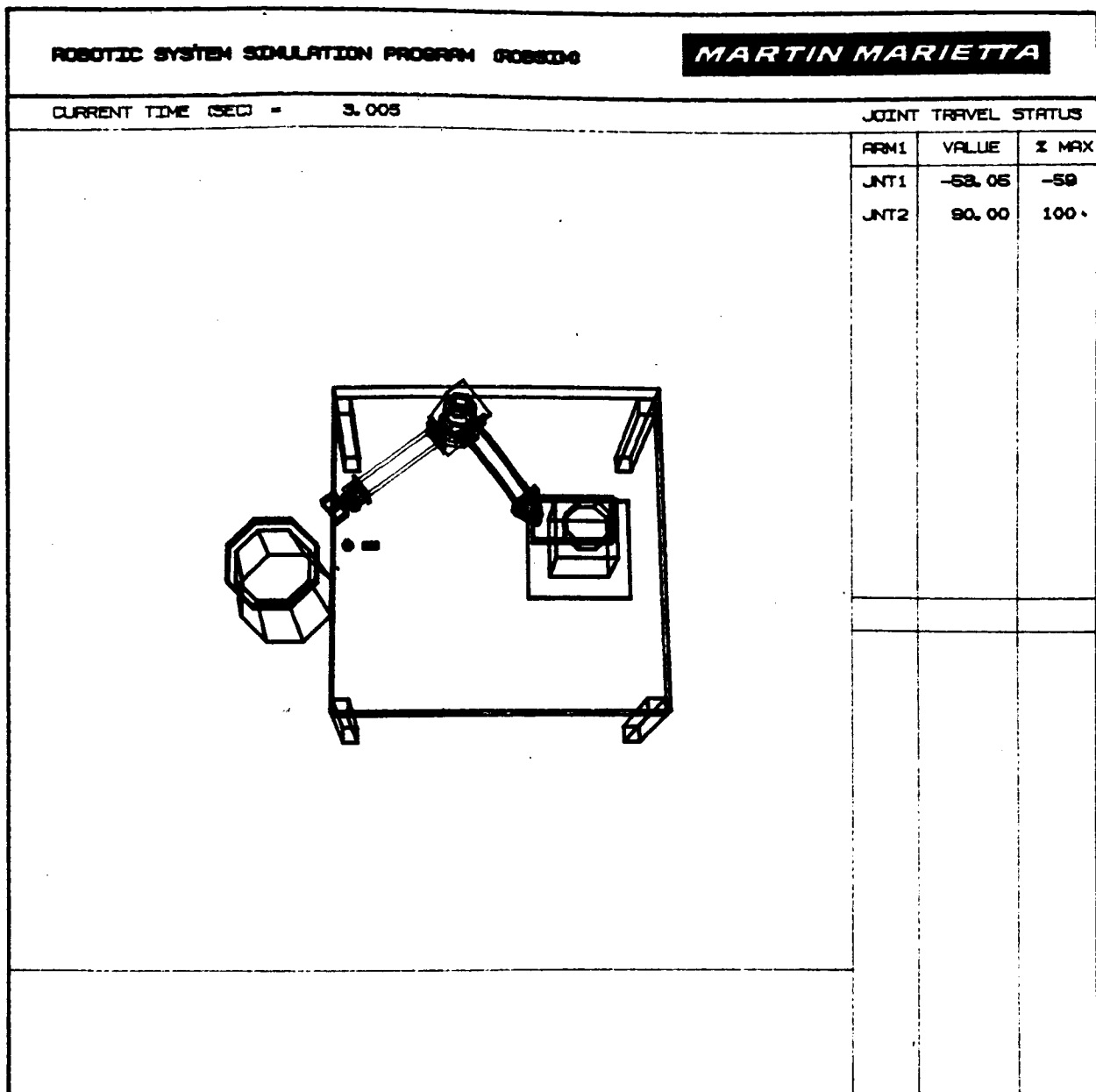


Figure A-34. - Postprocessor motion replay display at $t = 3$ second.

Simulation vs Hardware Motion Replay Procedure

In the postprocessor function there resides another option that provides a replay of the robotic system motion produced during the requirements/simulation analysis tools function versus the actual motion that occurred during the corresponding hardware run. The advantage of this option is the replay of the requirements or simulation graphics for a quicker display of the motion that occurred in the prior processor run, and the matching of hardware joint theta values for simulation validation. A graphics package shows the superimposed motion. During this option, the user is prompted for the system geometry ('.SYS') file to be used for display, the name of the file containing the data generated during the analysis tools function execution ('.SOF') and the name of the hardware file ('.THT') containing joint theta values for each time step.

The user input for the system geometry to display is given by:

```
ENTER FILENAME OF SYSTEM DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANDET.SYS
```

and, the corresponding simulation output file to replay is specified with:

```
ENTER FILENAME OF SIMULATION OUTPUT FILE
WHICH CORRESPONDS TO THE REQUESTED
SIMULATION INPUT FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANSIM.SOF
```

and the hardware joint angles file to use should be input at:

```
ENTER FILENAME OF HARDWARE THETA INPUT DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40
EXAMPLE - ROBDEVICE:[ROBDIR]PLANAR.THT
```

The graphics robotic arms, environment and load object data blocks will be used directly to display the Evans and Sutherland picture. The graphics system is displayed in the initialized state. The postprocessing data file and hardware theta file are read for each time step to obtain the joint displacements for hardware and simulation, and then the displacements are read at each time step to update the system motion detailed. A comparison of the hardware and simulation joint theta values is observed. The real hardware motion is defined by a spline displayed in the graphics; it represents the theta values desired of the simulation. The error in the joint angles may be considered as the angular difference in the centerline of each simulated graphics link and the red-line projection of that hardware theta value. In concluding, all data files are closed, and the display is terminated.

The display is scaled with the stored COMMON variable, system span, that was chosen while creating the robotic system scenario during the system definition function. The simulation joint positions and orientations, along with the actual joint hardware translation position vectors and the rotation matrices (from joint coordinate systems to the inertial system), are loaded by an internal program method for hardware and simulation, in turn. The form of the graphics picture output is bordered on the right with columns showing the current processing time joint angles (degrees) in column 1 and the percent of the maximum displacement permissible (that is presently traversed) for each joint of each arm, in column 2. The current simulation processing time is accrued at the top of the display, and the run title and Martin Marietta logo printed. In the update mode, the environment and the arm bases displayed are constant and therefore not changed.

Each individual joint theta value is read from the hardware control theta values file for each simulation time step. There is a limit of one theta signal value for each joint that can be read per step. A theta value best estimation with time is accomplished through linear interpolation.

The hardware theta file is created through execution of a liaison program utility. This independent program converts hardware theta (or joint control voltage) files directly written from execution of the case-select 3-link planar arm hardware designed and built by Martin Marietta Denver Aerospace and used for preliminary validation of the ROBSIM implementation, to a single time-tagged file formatted for use by the ROBSIM program. In the case of the hardware control voltage output file, the converted data file may be employed by the response simulation driver. The reformatted hardware motion theta value file is necessary, however, for the hardware vs simulation motion postprocessing option. For a user outline of the convert hardware extension, see the subsection entitled Running the hardware conversion program.

Load object grasp and release commands are preprogrammed and read from the simulation output file. Such actions are designated for performance at a particular simulation time step, and are affiliated with a particular load object in the system scenario. The SOF includes a load flag to signify the grasp or release time-tagged events.

During grasping an object, the program adds the load mass properties to that of the arm end-effector to simulate a load object assumed at the robot tool. This procedure first checks to see that the arm is not already holding a load object or that another arm is not holding the desired load object. If these conditions are satisfied, the vector from the tool origin to the load center of gravity (in the tool coordinate system) is calculated, as well as the inertia matrix of the load in the tool coordinate system. The load mass properties are combined with those of the tool, and stored in tool variables. Here it is assumed that the arm is in a position that would enable it to grasp the load object, and that the load object will not slip after being held and moved by the arm. It is also assumed that the tool is centered about the object being grasped so no adjustments need to be made while the arm is grasping the load object.

The arm simulates releasing a load object by resetting the tool mass properties and updating the load object location and orientation. It checks if the arm is holding an object that it can release. If this is the case, the tool mass properties (mass, center of gravity, and inertia matrix) are reset to the values they were assigned before picking up the load object, and the load location and orientation are calculated for the place the load was set down. It is assumed that the object will stay where released.

As a beginning step, the user signifies the start of dynamic motion by depressing the RETURN key:

ENTER RETURN TO BEGIN MOTION

During the playback, the user will be allowed the use of an Evans and Sutherland extended function key reserved for cessation of system playback motion. While extended switch number 0 is activated, simulation playback time is halted and the user is allowed the freedom to change the translational, rotational and zoom perspectives of the displayed picture through movement of the E&S extended analog dials. When analysis in this manner is complete, depressing the same function key number 0 resumes playback motion and simulation time continues updating. A light indicator in the function key is used to inform the user of the key status; when lighted, the perspective viewing is in operation.

After the graphics execution is complete the user encounters:

ENTER RETURN TO TERMINATE GRAPHICS AND CONTINUE

At completion of motion replay, the user is asked whether a hardcopy printout meta-file should be written for regeneration on the Hewlett-Packard x-y plotter. If it is wished to create a paper copy of the final graphics display, the user should input a file name prefix for the answer to the hardcopy question, otherwise RETURN. The file prefix will be appended with '.PIC' and saved in the user directory. For instructions on exercising the meta-file output routine, see the notes to this effect in the user's guide introduction.

In summary, during the motion graphics capability of this postprocessing option, a replay of the simulation motion is apparent with the movement of the designed robot graphics, and lines are displayed to represent the theoretical motions for each link. The value of the difference in the simulation thetas and hardware thetas is useful in the correlation analysis of the simulation motion with the actual corresponding hardware motion. The current simulation joint angles are output for each processing time step.

Sample run. - The next pages are provided as an example (Example A-12) that implements the simulation vs hardware option. Refer to Figure A-35 for a visual representation of the simulation vs hardware motion display.

Example A-12

ROBOTIC SYSTEM SIMULATION PROGRAM (ROBSIM)

ENTERING POST PROCESSING FUNCTION

DEFAULT LOGICAL UNIT ASSIGNMENTS USED WITHIN ROBSIM

LU	USE
5	READ UNIT (TERMINAL)
6	WRITE UNIT (TERMINAL)
7	PRINTED OUTPUT UNIT
8-9	SIMULATION INPUT FILE
10	SIMULATION OUTPUT FILE
11	ACTUATOR PARAMETERS INPUT FILE
14	LOAD OBJECTS DATA FILE
15	ERROR MESSAGE FILE
16	GAIN CONSTANTS FILE
17	TORQUE DATA INPUT FILE
18	ACC-VEL-THETA FILE
19	PROGRAMS OPTIONS FILE
20	PLOT DATA FILE
21	MOTION TIME HISTORY FILE
22	HARDWARE CONTROL SIGNALS
23	CONTROL OPTIONS INPUT FILE
24	CONTROL MODULE OUTPUT FILE

USER WILL BE PROMPTED FOR FILENAMES
TO ASSOCIATE WITH EACH LOGICAL UNIT
WHEN REQUIRED

ENTER RETURN TO CONTINUE

<CR>

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REPLAY GRAPHIC SIMULATION MOTION ONLY
2	REPLAY GRAPHIC SIMULATION VERSUS HARDWARE MOTION
3	PARAMETER VERSUS PARAMETER PLOTS
4	TERMINATE POST PROCESSOR EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

2

ENTER FILENAME OF SYSTEM DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40

EXAMPLE - ROBDEVICE:[ROBDIR]PLANDET.SYS
PLANDET.SYS

SYSTEM DATA FILE HAS BEEN READ
ALL COMMON BLOCKS ARE LOADED

ENTER FILENAME OF SIMULATION OUTPUT FILE
WHICH CORRESPONDS TO THE REQUESTED
SIMULATION INPUT FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40

EXAMPLE - ROBDEVICE:[ROBDIR]PLANSIM.SOF
PLANAR.SOF

ENTER FILENAME OF HARDWARE THETA INPUT DATA FILE
THE TOTAL NUMBER OF CHARACTERS IN FILENAME
CAN NOT EXCEED 40

EXAMPLE - ROBDEVICE:[ROBDIR]PLANAR.THT
PLANAR2.THT

ENTER RETURN TO BEGIN MOTION

<CR>

ENTER RETURN TO TERMINATE GRAPHICS AND CONTINUE

<CR>

*** HARD COPY ***

ENTER ".PIC" FILE NAME PREFIX
(<CR|=NONE) :PLNDET4
FILE "PLNDET4.PIC" OPENED

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REPLAY GRAPHIC SIMULATION MOTION ONLY
2	REPLAY GRAPHIC SIMULATION VERSUS HARDWARE MOTION
3	PARAMETER VERSUS PARAMETER PLOTS
4	TERMINATE POST PROCESSOR EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

4

EXITING FROM POST PROCESSING FUNCTION

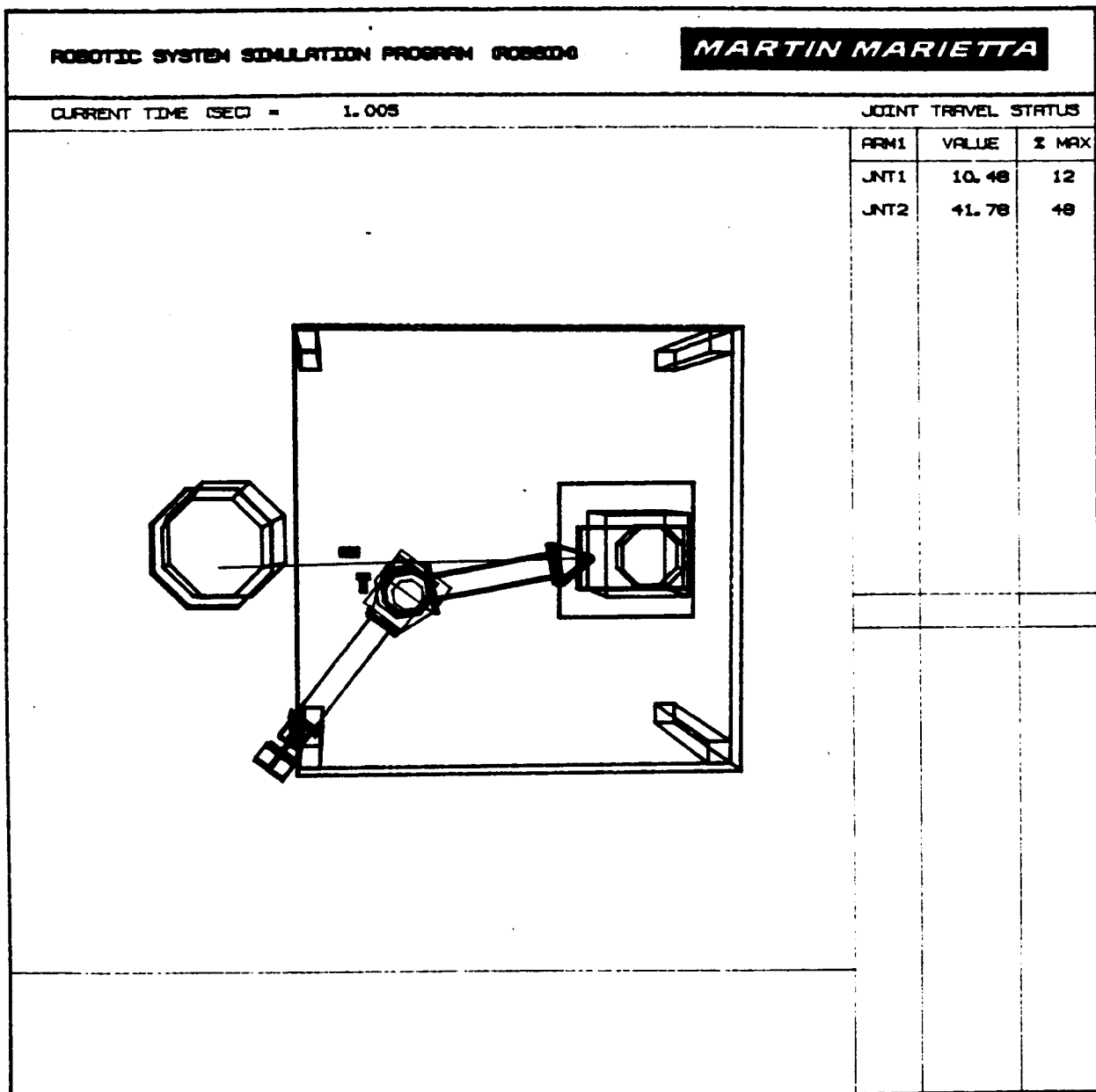


Figure A-35. - Postprocessor hardware vs simulation motion at $t = 1$ second.

Running the hardware conversion program. - This is a description of the convert hardware program developed for converting the specific Martin Marietta Denver Aerospace planar arm output to a format construction used by the ROBSIM voltage or theta value input routines.

After typing RUN CNVTHRDW, the user is given the option for the conversion program operation to be applied. The prompt answer for this mode should be chosen as:

WHAT TYPE OF HARDWARE DATA DO YOU WISH TO CONVERT?
1 FOR HARDWARE CONTROL SIGNAL FILE
2 FOR HARDWARE THETA FILE

The successive input deliberations are described in the following sequence of entries. They are:

ENTER START TIME FOR TIME TAGGING OF HARDWARE FILE

ENTER STOP TIME FOR TIME TAGGING HARDWARE FILE

and, the time step size (it should match the robotic simulation program processing step size):

ENTER STEP SIZE (A REAL NUMBER)

Then, the number of arms worth of hardware data in the file to be converted and the available number of hardware voltage or theta files worth of joint data for each arm are entered at:

HOW MANY ARMS WORTH OF HARDWARE DATA?

and, if theta conversion was opted:

HOW MANY FILES OF HARDWARE JOINT THETA
VALUES FOR ARM 1?
HOW MANY FILES OF HARDWARE JOINT VOLTAGE
VALUES FOR ARM 2?
(etc., for each existent arm)

else, if voltage conversion was chosen:

HOW MANY FILES OF HARDWARE JOINT VOLTAGE
VALUES FOR ARM 1?
HOW MANY FILES OF HARDWARE JOINT VOLTAGE
VALUES FOR ARM 2?
(etc., for each existent arm)

The prompts are then designed for the input of the file names of the hardware voltage or theta files to be read. For each arm, the user responds to:

```
ENTER NAME OF FILE WITH HARDWARE THETA VALUES
FOR JOINT 1
ENTER NAME OF FILE WITH HARDWARE THETA VALUES
FOR JOINT 2
(etc., for each joint)
```

or, for the interim voltage file saved from the hardware:

```
ENTER NAME OF FILE WITH HARDWARE VOLTAGE VALUES
FOR JOINT 1
ENTER NAME OF FILE WITH HARDWARE VOLTAGE VALUES
FOR JOINT 2
(etc., for each joint)
```

For the output storage of the converted data that will be an input to the postprocessing (if theta values), or analysis tools (if voltage values), function, answer:

```
ENTER NAME OF HARDWARE [theta or voltage] FILE TO WRITE
```

The control signal files generated are by convention usually given the appendage '.VLT' (for voltage), and for the theta signal files generated it is customary to use '.THT' (for theta). A series of files are opened for reading or writing beginning at one addressed logical unit number, for each of these three file types, and incrementing the unit number value for each joint file needed.

For the planar arm, the hardware data files are either angular position data or 12-bit DAC data. The position value is a 12-bit number corresponding to an angle between 0 and 359.999999999. The position data are converted from the 12-bit RTD data to an angle between ± 90 degrees. The DAC data are in the form of a 12-bit two's complement number. The DAC data are converted to a real number representing a voltage between ± 10 volts. A file is generated from the planar arm output module; this file contains a header (giving information about the data) followed by three columns of data.

For the angular position data, the columns are:

- i. RAW DATA VALUE
- ii. ANGLE IN DEGREES
- iii. ANGLE IN RADIANS

For the DAC data the columns are:

- i. RAW DATA VALUE
- ii. CONVERTED VALUE BETWEEN ± 2047 .
- iii. VOLTAGE IN VOLTS

The format used by the convert hardware program interfaces with a hardware output file of this type. The hardware conversion utility reads the data that in this case are specific to the Martin Marietta 3-link planar arm, and extracts the column of information needed in the ROBSIM program. This routine will need to be modified to fit the particular installation hardware system program used to create the output data files (for both RTD data and DAC data).

Parameter versus Parameter Plot Package Procedure

The ROBSIM parameter plotting option plots the contents of one of several choices for plot package formats on a Hewlett-Packard x-y plotter or a VAX VT125 graphics port. It uses exclusively the DI3000 plot package of Fortran-callable routines. Called when the parameter versus parameter plotting option is chosen during postprocessing, this option requests the user select one of seven predesigned plot file types that are written at user's discretion during the requirements or simulation analysis tools function:

- 1) The brief package;
- 2) The end-effector package;
- 3) The joint positions package;
- 4) The reaction forces package;
- 5) The combination of above four packages;
- 6) The PID control package;
- 7) The force/torque control package.

A flag input during the analysis tools function specifying the plot file type is saved in the header information for each plot file written. By extracting the header information, it is possible for the program to inform the user of the format for the chosen plot file and to print the header information about the type of values contained in the file at the user's terminal.

First, the user is asked to terminate the plot routine if the appropriate device setup commands have not been issued (a 1 entered here will cause an exit from the current plot process). Depressing the RETURN key will continue the plotting option. A series of terminal inputs while performing the postprocessing plot option then needs to be responded to in the following manner, respectively.

The file name of the existing plot file should be input for:

ENTER NAME OF FILE CONTAINING DATA FOR PLOTS
MAX OF 40 CHARACTERS EXAMPLE - ROBDEVICE:[ROBDIR]PLANSIM.PLT

and, the user option for automatic scaling (the scale to be determined within the program) or to input scaling information from the terminal is given by:

DO YOU WISH AUTOMATIC SCALING?
ENTER Y FOR YES
ENTER N FOR NO

The user will then be asked for the series of (arm, joint, parameter) value sets describing the curves to be displayed on this plot. The maximum number of curves that can be displayed on one plot is equal to the (number of arms)*(number of joints)*(number of data parameters) saved in the plot file. The values desired for plotting should be characterized as shown here and prompted for each curve desired.

The actual array of arms chosen by the user for plotting parameters is loaded with:

THERE ARE K ARMS IN THIS SYSTEM

ARM 1 HAS N JOINTS
ARM 2 HAS N1 JOINTS
(etc., for each existent arm)

FOR WHICH ARM WOULD YOU LIKE TO PLOT VALUES?
INPUT 0 WHEN FINISHED ENTERING ALL PLOTS
TO BE DRAWN FROM THIS PLOT FILE.

and, for the actual array of joints for plotting these parameters:

FOR WHICH JOINT OF ARM J WOULD YOU LIKE TO PLOT VALUES?
FOR END-EFFECTOR VALUES, ENTER VALUE THAT IS
ONE MORE THAN THE NUMBER OF JOINTS.
IF NOT A JOINT OR END-EFFECTOR VALUE, ENTER ZERO.

Then, the generic format for the parameter header output and question dealing with particular choice of parameter value to plot, corresponding to the aforementioned (arm, joint) pair, appears as:

THERE ARE L Y VALUES AVAILABLE FOR PLOTTING.
ENTRY 1 IS [the first parameter name]
ENTRY 2 IS [the second parameter name]

(etc.)

ENTER Y VALUE TO BE PLOTTED

Note that there is a maximum number of allowable robot arms, a maximum number of allowable links per arm, a maximum number of curves per plot, and a maximum number of Y array plot data parameters allowed to be written to any one plot file. These default values are saved in a modifiable file. All of the curves will be plotted against the independent X variable, time.

The next inquiries are used for scaling the axes of the plot. If the user has opted for the interactive definition mode of scaling the plot, as opposed to automatic scaling, the succeeding prompts will be to input the X array minimum and maximum values to use for scaling the x-axis and the Y array minimum and maximum values to use for scaling the y-axis. The user responds to:

INPUT HORIZONTAL DATA MIN AND MAX VALUES
ENTER AS REAL NUMBERS SEPARATED BY A COMMA

INPUT VERTICAL DATA MIN AND MAX VALUES
ENTER AS REAL NUMBERS SEPARATED BY A COMMA

The next inquiry deals with the necessary step size interval at which to output tic marks on the x-axis and y-axis (a real number, in plot units):

INPUT HORIZONTAL AND VERTICAL TICK MARK
INCREMENTS, IN PLOT UNITS
ENTER AS REAL NUMBERS SEPARATED BY A COMMA

Next, the entries represent the interval for the frequency while labeling the x and y axes tic marks. The step sizes to be used for the x-axis and the y-axis tic mark labels should be specified as the real number plot interval at which they should have value assignments (in plot units). Answer:

LABEL X-AXIS TICKS EVERY HOW MANY
TICK MARK INCREMENTS, IN PLOT UNITS
ENTER AS A REAL NUMBER

and

LABEL Y-AXIS TICS EVERY HOW MANY
TICK MARK INCREMENTS, IN PLOT UNITS
ENTER AS A REAL NUMBER

In conclusion, the plot title and axes labeling text are pursued. The questions encountered are:

ENTER DESIRED PLOT TITLE
MAXIMUM OF 40 CHARACTERS
*** LAST CHARACTER MUST BE "\$" ***

and

ENTER DESIRED HORIZONTAL (X) AXIS LABEL
MAXIMUM OF 40 CHARACTERS
*** LAST CHARACTER MUST BE "\$" ***

and

ENTER DESIRED VERTICAL (Y) AXIS LABEL
MAXIMUM OF 40 CHARACTERS
*** LAST CHARACTER MUST BE "\$" ***

A symbol dollar sign should be included at the end of each typed title and axes labels input, signifying end of the character string title or label. It is needed for centering the text and, if omitted, the characters will be left-justified at the output location.

Before each curve displayed during plotting, the user will be asked for a decision as to plotting the curve in a continuous or point plot fashion:

ENTER 1 FOR CONTINUOUS CURVE
ENTER 2 TO PLOT AS POINTS

At this point the curves are output to the peripheral device for plotting. The x and y axes are drawn, and an appropriate scale by which to label the axes is chosen. Input to the scaling routine are the number of intervals into which each axis should be divided (this is hard-coded to 10 sections on the x-axis and 7 sections on the y-axis for the automatic scaling mode) and the flag selecting automatic or specific scaling. The exponent of the scale base, the tic mark spacing, or step size, and the minimum tic mark values are computed by the same process for both automatic and user-specified scaling. The minimum value, XI, to be used for the scale, and DX, the scale increment between tic marks, are chosen to satisfy the following constraints:

- A) $XI(\text{initial x-axis tic value}) \leq XMIN(\text{the x minimum})$
- B) $[XI + ANX(\text{the number of axis tic mark intervals}) * DX(\text{the step size})] \geq XMAX(\text{the x maximum})$
- C) $DX = 1, 2, 4, 5, \text{ or } 8 \text{ times a power of } 10.$
- D) XI is an integral multiple of DX
- E) $ANX * DX$ is a minimum

In searching the file for maximum and minimum values to use in scaling the axes of the plot, the whole plot file is read by a routine, and the total X and Y minimum and maximum are found for the set of parameters the user has pre-chosen for plotting. The values for the variables not being plotted are read into dummy arrays. If the minimum and maximum for an axis are both found to be

zero, a value of -0.001 is assigned to the minimum and 0.001 assigned to the maximum. An attempt to center the curves on the plot involves taking 10 percent of the range of the values and subtracting it from the true parameter minimum and adding it to the true parameter maximum.

The brief plot package. - This plot file can be written by the requirements or simulation analysis tools function. If the user chooses the brief plot package format for plotting, the parameters available for display are the basic robotic state values:

Joint angular displacements,
Joint angular velocities,
Joint angular accelerations,
Drive torques.

The header record on this file contains information for printout to the user's terminal that will allow a view of the data array order of the plot file. The text header appears as:

ENTRY 1 IS THE THETA VALUE
ENTRY 2 IS THE THETA DOT VALUE
ENTRY 3 IS THE THETA DOUBLE DOT VALUE
ENTRY 4 IS THE ACTUATOR TORQUE VALUE (for requirements)

ENTRY 1 IS THE THETA VALUE
ENTRY 2 IS THE THETA DOT VALUE
ENTRY 3 IS THE THETA DOUBLE DOT VALUE
ENTRY 4 IS THE DRIVE TORQUE VALUE (for response simulation)

The end-effector plot package. - This plot file can be written by the requirements or simulation analysis tools function. The end-effector package concerns the robot tool specification and includes:

End-effector translational position,
Force vector at the end-effector,
Torque vector at the end-effector.

This plot package description header record will print as:

ENTRY 1 IS THE END-EFF. X POSITION
ENTRY 2 IS THE END-EFF. Y POSITION
ENTRY 3 IS THE END-EFF. Z POSITION
ENTRY 4 IS THE END-EFF. X FORCE
ENTRY 5 IS THE END-EFF. Y FORCE
ENTRY 6 IS THE END-EFF. Z FORCE
ENTRY 7 IS THE END-EFF. X TORQUE
ENTRY 8 IS THE END-EFF. Y TORQUE
ENTRY 9 IS THE END-EFF. Z TORQUE

The joint positions plot package. - This plot file can be written by the requirements or simulation analysis tools function. This plot file version entails only:

Translational joint positions.

The text header that will be written to the terminal to assist the user in making a decision of the parameter(s) for plot, will be:

ENTRY 1 IS THE JOINT X POSITION VALUE
ENTRY 2 IS THE JOINT Y POSITION VALUE
ENTRY 3 IS THE JOINT Z POSITION VALUE

The reaction forces plot package. - This plot file can be written by the requirements or simulation analysis tools function. The reaction forces plot file is portrayed as:

Force joint vectors,
Torque joint vectors.

The header description encountered is:

ENTRY 1 IS THE JOINT FORCE X VALUE
ENTRY 2 IS THE JOINT FORCE Y VALUE
ENTRY 3 IS THE JOINT FORCE Z VALUE
ENTRY 4 IS THE JOINT TORQUE X VALUE
ENTRY 5 IS THE JOINT TORQUE Y VALUE
ENTRY 6 IS THE JOINT TORQUE Z VALUE

The combination plot package. - This plot file can be written by the requirements or simulation analysis tools function. It writes all of the parameters in all of the four packages explained above:

Joint angular displacements,
Translational joint positions,
Joint angular velocities,
Joint angular accelerations,
Force joint vectors,
Torque joint vectors,
Drive torques,
End-effector translational position,
Force vector at the end-effector,
Torque vector at the end-effector.

The header record contains:

ENTRY 1 IS THE THETA VALUE
ENTRY 2 IS THE JOINT X POS. VALUE
ENTRY 3 IS THE JOINT Y POS. VALUE
ENTRY 4 IS THE JOINT Z POS. VALUE
ENTRY 5 IS THE THETA DOT VALUE
ENTRY 6 IS THE THETA DOUBLE DOT VALUE
ENTRY 7 IS THE JOINT X FORCE VALUE

ENTRY 8 IS THE JOINT Y FORCE VALUE
 ENTRY 9 IS THE JOINT Z FORCE VALUE
 ENTRY 10 IS THE JOINT X TORQUE VALUE
 ENTRY 11 IS THE JOINT Y TORQUE VALUE
 ENTRY 12 IS THE JOINT Z TORQUE VALUE
 ENTRY 13 IS THE ACTUATOR TORQUE VALUE (for requirements)
 or
 ENTRY 13 IS THE DRIVE TORQUE VALUE (for response simulation)
 ENTRY 14 IS THE END-EFF. X POSITION
 ENTRY 15 IS THE END-EFF. Y POSITION
 ENTRY 16 IS THE END-EFF. Z POSITION
 ENTRY 17 IS THE END-EFF. X FORCE
 ENTRY 18 IS THE END-EFF. Y FORCE
 ENTRY 19 IS THE END-EFF. Z FORCE
 ENTRY 20 IS THE END-EFF. X TORQUE
 ENTRY 21 IS THE END-EFF. Y TORQUE
 ENTRY 22 IS THE END-EFF. Z TORQUE

The PID control plot package. - This plot file can be written by the simulation analysis tools function only. The format is:

Amplifier voltages,
 Joint reference positions,
 Joint position errors,
 End-effector reference position,
 End-effector position error.

In describing the PID control effects, the header record plot parameter choices are as follows:

ENTRY 1 IS THE AMPLIFIER VOLTAGE VALUE
 ENTRY 2 IS THE JOINT REFERENCE ANGLE
 ENTRY 3 IS THE JOINT POSITION ERROR
 ENTRY 4 IS THE END-EFF. REF. X POSITION
 ENTRY 5 IS THE END-EFF. REF. Y POSITION
 ENTRY 6 IS THE END-EFF. REF. Z POSITION
 ENTRY 7 IS THE END-EFF. X POS. ERROR
 ENTRY 8 IS THE END-EFF. Y POS. ERROR
 ENTRY 9 IS THE END-EFF. Z POS. ERROR
 ENTRY 10 IS END-EFF. X ROT. POS. ERROR
 ENTRY 11 IS END-EFF. Y ROT. POS. ERROR
 ENTRY 12 IS END-EFF. Z ROT. POS. ERROR

The force/torque plot package. - This plot file can be written by the the simulation analysis tools function only. The force/torque references are limited to the list of variables:

Amplifier voltages,
 Reference position,
 Reference force,
 End-effector translational position,
 Force vector at the end-effector,
 Torque vector at the end-effector,
 Error in position,
 Error in force/torque.

The actual arrangement of the parameters for plot consideration with this file are:

ENTRY 1 IS THE AMPLIFIER VOLTAGE VALUE
ENTRY 2 IS THE REF. X POSITION VALUE
ENTRY 3 IS THE REF. Y POSITION VALUE
ENTRY 4 IS THE REF. Z POSITION VALUE
ENTRY 5 IS THE USER GIVEN REF. X FORCE
ENTRY 6 IS THE USER GIVEN REF. Y FORCE
ENTRY 7 IS THE USER GIVEN REF. Z FORCE
ENTRY 8 IS REF. FORCE ROT. VECT. X
ENTRY 9 IS REF. FORCE ROT. VECT. Y
ENTRY 10 IS REF. FORCE ROT. VECT. Z
ENTRY 11 IS THE END-EFF. X POSITION
ENTRY 12 IS THE END-EFF. Y POSITION
ENTRY 13 IS THE END-EFF. Z POSITION
ENTRY 14 IS THE END-EFF. X FORCE
ENTRY 15 IS THE END-EFF. Y FORCE
ENTRY 16 IS THE END-EFF. Z FORCE
ENTRY 17 IS THE END-EFF. X TORQUE
ENTRY 18 IS THE END-EFF. Y TORQUE
ENTRY 19 IS THE END-EFF. Z TORQUE
ENTRY 20 IS THE ERROR IN X POSITION
ENTRY 21 IS THE ERROR IN Y POSITION
ENTRY 22 IS THE ERROR IN Z POSITION
ENTRY 23 IS ERROR IN POS. X ROT. VALUE
ENTRY 24 IS ERROR IN POS. Y ROT. VALUE
ENTRY 25 IS ERROR IN POS. Z ROT. VALUE
ENTRY 26 IS THE ERROR IN X FORCE/TORQUE
ENTRY 27 IS THE ERROR IN Y FORCE/TORQUE
ENTRY 28 IS THE ERROR IN Z FORCE/TORQUE
ENTRY 29 IS ERROR IN X ROT. FORCE/TORQUE
ENTRY 30 IS ERROR IN Y ROT. FORCE/TORQUE
ENTRY 31 IS ERROR IN Z ROT. FORCE/TORQUE

Sample run. - Samples of several of these plot types (Example A-13) are included, along with a printout of the runtime prompts that generated them. Figures A-36 through A-38 are the plots obtained from the interactive run.

Example A-13

ROBOTIC SYSTEM SIMULATION PROGRAM (ROBSIM)

ENTERING POST PROCESSING FUNCTION

DEFAULT LOGICAL UNIT ASSIGNMENTS USED WITHIN ROBSIM

LU	USE
5	READ UNIT (TERMINAL)
6	WRITE UNIT (TERMINAL)
7	PRINTED OUTPUT UNIT
8-9	SIMULATION INPUT FILE
10	SIMULATION OUTPUT FILE
11	ACTUATOR PARAMETERS INPUT FILE
14	LOAD OBJECTS DATA FILE
15	ERROR MESSAGE FILE
16	GAIN CONSTANTS FILE
17	TORQUE DATA INPUT FILE
18	ACC-VEL-THETA FILE
19	PROGRAMS OPTIONS FILE
20	PLOT DATA FILE
21	MOTION TIME HISTORY FILE
22	HARDWARE CONTROL SIGNALS
23	CONTROL OPTIONS INPUT FILE
24	CONTROL MODULE OUTPUT FILE

USER WILL BE PROMPTED FOR FILENAMES
TO ASSOCIATE WITH EACH LOGICAL UNIT
WHEN REQUIRED

ENTER RETURN TO CONTINUE

<CR>

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REPLAY GRAPHIC SIMULATION MOTION ONLY
2	REPLAY GRAPHIC SIMULATION VERSUS HARDWARE MOTION
3	PARAMETER VERSUS PARAMETER PLOTS
4	TERMINATE POST PROCESSOR EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

3

THIS PROGRAM USES THE DI3000 GRAPHICS SYSTEM
THE FOLLOWING SETUP PROCEDURES MUST HAVE BEEN
PERFORMED:

RUN THE COMMAND FILE FOR DI3000 SETUP:
@SYS_DI:DI3000
FOR HP 7221 PLOTTING RUN COMMAND FILE:
HPSETUP
FOR VT125 PLOTTING RUN COMMAND FILE:
VTSETUP

ENTER 1 TO TERMINATE PLOT SUBROUTINE IF THIS
HAS NOT BEEN DONE

ENTER RETURN TO CONTINUE

<CR>

ENTER NAME OF FILE CONTAINING DATA FOR PLOTS
MAX OF 40 CHARACTERS EXAMPLE - ROBDEVICE:[ROBDIR]PLANSIM.PLT
PLNDET5.PLT

DO YOU WISH AUTOMATIC SCALING?
ENTER Y FOR YES
ENTER N FOR NO

Y

THERE ARE 1 ARMS IN THIS SYSTEM

ARM 1 HAS 2 JOINTS

FOR WHICH ARM WOULD YOU LIKE TO PLOT VALUES?
INPUT 0 WHEN FINISHED ENTERING ALL PLOTS
TO BE DRAWN FROM THIS PLOT FILE.

1

FOR WHICH JOINT OF ARM 1 WOULD YOU LIKE TO PLOT VALUES?
FOR END-EFFECTOR VALUES, ENTER VALUE THAT IS
ONE MORE THAN THE NUMBER OF JOINTS.
IF NOT A JOINT OR END-EFFECTOR VALUE, ENTER ZERO.

1

THERE ARE 22 Y VALUES AVAILABLE FOR PLOTTING.

ENTRY 1 IS THE THETA VALUE
ENTRY 2 IS THE JOINT X POS. VALUE
ENTRY 3 IS THE JOINT Y POS. VALUE
ENTRY 4 IS THE JOINT Z POS. VALUE
ENTRY 5 IS THE THETA DOT VALUE
ENTRY 6 IS THE THETA DOUBLE DOT VALUE
ENTRY 7 IS THE JOINT X FORCE VALUE
ENTRY 8 IS THE JOINT Y FORCE VALUE
ENTRY 9 IS THE JOINT Z FORCE VALUE
ENTRY 10 IS THE JOINT X TORQUE VALUE
ENTRY 11 IS THE JOINT Y TORQUE VALUE
ENTRY 12 IS THE JOINT Z TORQUE VALUE
ENTRY 13 IS THE DRIVE TORQUE VALUE
ENTRY 14 IS THE END-EFF. X POSITION
ENTRY 15 IS THE END-EFF. Y POSITION
ENTRY 16 IS THE END-EFF. Z POSITION
ENTRY 17 IS THE END-EFF. X FORCE
ENTRY 18 IS THE END-EFF. Y FORCE
ENTRY 19 IS THE END-EFF. Z FORCE
ENTRY 20 IS THE END-EFF. X TORQUE
ENTRY 21 IS THE END-EFF. Y TORQUE
ENTRY 22 IS THE END-EFF. Z TORQUE

13 ENTER Y VALUE TO BE PLOTTED

FOR WHICH ARM WOULD YOU LIKE TO PLOT VALUES?
INPUT 0 WHEN FINISHED ENTERING ALL PLOTS
TO BE DRAWN FROM THIS PLOT FILE.

1

FOR WHICH JOINT OF ARM 1 WOULD YOU LIKE TO PLOT VALUES?
FOR END-EFFECTOR VALUES, ENTER VALUE THAT IS
ONE MORE THAN THE NUMBER OF JOINTS.
IF NOT A JOINT OR END-EFFECTOR VALUE, ENTER ZERO.

2

THERE ARE 22 Y VALUES AVAILABLE FOR PLOTTING.
ENTRY 1 IS THE THETA VALUE
ENTRY 2 IS THE JOINT X POS. VALUE
ENTRY 3 IS THE JOINT Y POS. VALUE
ENTRY 4 IS THE JOINT Z POS. VALUE
ENTRY 5 IS THE THETA DOT VALUE
ENTRY 6 IS THE THETA DOUBLE DOT VALUE
ENTRY 7 IS THE JOINT X FORCE VALUE
ENTRY 8 IS THE JOINT Y FORCE VALUE
ENTRY 9 IS THE JOINT Z FORCE VALUE
ENTRY 10 IS THE JOINT X TORQUE VALUE
ENTRY 11 IS THE JOINT Y TORQUE VALUE
ENTRY 12 IS THE JOINT Z TORQUE VALUE
ENTRY 13 IS THE DRIVE TORQUE VALUE
ENTRY 14 IS THE END-EFF. X POSITION
ENTRY 15 IS THE END-EFF. Y POSITION
ENTRY 16 IS THE END-EFF. Z POSITION
ENTRY 17 IS THE END-EFF. X FORCE
ENTRY 18 IS THE END-EFF. Y FORCE
ENTRY 19 IS THE END-EFF. Z FORCE
ENTRY 20 IS THE END-EFF. X TORQUE
ENTRY 21 IS THE END-EFF. Y TORQUE
ENTRY 22 IS THE END-EFF. Z TORQUE

13 ENTER Y VALUE TO BE PLOTTED

FOR WHICH ARM WOULD YOU LIKE TO PLOT VALUES?
INPUT 0 WHEN FINISHED ENTERING ALL PLOTS
TO BE DRAWN FROM THIS PLOT FILE.

0

ENTER DESIRED PLOT TITLE
MAXIMUM OF 40 CHARACTERS
*** LAST CHARACTER MUST BE "\$" ***
TIME VS. JOINT DRIVE TORQUES\$

ENTER DESIRED HORIZONTAL (X) AXIS LABEL
MAXIMUM OF 40 CHARACTERS

*** LAST CHARACTER MUST BE "\$" ***

TIME\$

ENTER DESIRED VERTICAL (Y) AXIS LABEL
MAXIMUM OF 40 CHARACTERS

*** LAST CHARACTER MUST BE "\$" ***

JOINT 1 AND JOINT 2 DRIVE TORQUES\$

***** DI-3000 ... HP 7221 DEVICE DRIVER *****

Please enter paper size (1 OR 2)

(1) --- 11 BY 8 1/2 INCHES (DEFAULT)

(2) --- 16 1/2 BY 11 INCHES

1

Please enter pen velocity (1, 2, or 3)

(1) --- 10 CM/SEC

(2) --- 20 CM/SEC

(3) --- 36 CM/SEC (DEFAULT)

2

PLEASE ENTER PAPER TYPE (1 OR 2)

(1) --- SINGLE SHEET - MANUAL FEED

(2) --- CONTINUOUS FEED ROLL (7221S ONLY)

FOR SINGLE SHEET YOU WILL BE PROMPTED TO ENTER A
NEW SHEET OF PAPER AFTER EACH PICTURE.

FOR CONTINUOUS FEED THE PAPER WILL ADVANCE AUTOMATICALLY AFTER EACH PICTURE

1

Ready for graphics. Please turn on plotter and
insert paper for first plot.

Hit [RETURN] when ready to continue

<CR>

ENTER 1 FOR CONTINUOUS CURVE

ENTER 2 TO PLOT AS POINTS

1

Pause requested. Hit [RETURN] to continue.

<CR>

ENTER 1 FOR CONTINUOUS CURVE

ENTER 2 TO PLOT AS POINTS

1

Pause requested. Hit [RETURN] to continue.

<CR>

Pause requested. Hit [RETURN] to continue.

<CR>

Normal termination. Please remove plot.

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REPLAY GRAPHIC SIMULATION MOTION ONLY
2	REPLAY GRAPHIC SIMULATION VERSUS HARDWARE MOTION
3	PARAMETER VERSUS PARAMETER PLOTS
4	TERMINATE POST PROCESSOR EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

3

THIS PROGRAM USES THE DI3000 GRAPHICS SYSTEM
THE FOLLOWING SETUP PROCEDURES MUST HAVE BEEN
PERFORMED:

RUN THE COMMAND FILE FOR DI3000 SETUP:

@SYS\$DI:DI3000

FOR HP 7221 PLOTTING RUN COMMAND FILE:

HPSETUP

FOR VT125 PLOTTING RUN COMMAND FILE:

VTSETUP

ENTER 1 TO TERMINATE PLOT SUBROUTINE IF THIS
HAS NOT BEEN DONE

ENTER RETURN TO CONTINUE

<CR>

ENTER NAME OF FILE CONTAINING DATA FOR PLOTS
MAX OF 40 CHARACTERS EXAMPLE - ROBDEVICE:[ROBDIR]PLANSIM.PLT
PLNDET6.PLT

DO YOU WISH AUTOMATIC SCALING?

ENTER Y FOR YES

ENTER N FOR NO

Y

THERE ARE 1 ARMS IN THIS SYSTEM

ARM 1 HAS 2 JOINTS

FOR WHICH ARM WOULD YOU LIKE TO PLOT VALUES?
INPUT 0 WHEN FINISHED ENTERING ALL PLOTS
TO BE DRAWN FROM THIS PLOT FILE.

1

FOR WHICH JOINT OF ARM 1 WOULD YOU LIKE TO PLOT VALUES?
FOR END-EFFECTOR VALUES, ENTER VALUE THAT IS
ONE MORE THAN THE NUMBER OF JOINTS.
IF NOT A JOINT OR END-EFFECTOR VALUE, ENTER ZERO.

1

THERE ARE 12 Y VALUES AVAILABLE FOR PLOTTING.
ENTRY 1 IS THE AMPLIFIER VOLTAGE VALUE
ENTRY 2 IS THE JOINT REFERENCE ANGLE
ENTRY 3 IS THE JOINT POSITION ERROR
ENTRY 4 IS THE END-EFF. REF. X POSITION
ENTRY 5 IS THE END-EFF. REF. Y POSITION
ENTRY 6 IS THE END-EFF. REF. Z POSITION
ENTRY 7 IS THE END-EFF. X POS. ERROR
ENTRY 8 IS THE END-EFF. Y POS. ERROR
ENTRY 9 IS THE END-EFF. Z POS. ERROR
ENTRY 10 IS END-EFF. X ROT. POS. ERROR
ENTRY 11 IS END-EFF. Y ROT. POS. ERROR
ENTRY 12 IS END-EFF. Z ROT. POS. ERROR

ENTER Y VALUE TO BE PLOTTED

2

FOR WHICH ARM WOULD YOU LIKE TO PLOT VALUES?
INPUT 0 WHEN FINISHED ENTERING ALL PLOTS
TO BE DRAWN FROM THIS PLOT FILE.

1

FOR WHICH JOINT OF ARM 1 WOULD YOU LIKE TO PLOT VALUES?
FOR END-EFFECTOR VALUES, ENTER VALUE THAT IS
ONE MORE THAN THE NUMBER OF JOINTS.
IF NOT A JOINT OR END-EFFECTOR VALUE, ENTER ZERO.

1

THERE ARE 12 Y VALUES AVAILABLE FOR PLOTTING.
ENTRY 1 IS THE AMPLIFIER VOLTAGE VALUE
ENTRY 2 IS THE JOINT REFERENCE ANGLE
ENTRY 3 IS THE JOINT POSITION ERROR
ENTRY 4 IS THE END-EFF. REF. X POSITION
ENTRY 5 IS THE END-EFF. REF. Y POSITION
ENTRY 6 IS THE END-EFF. REF. Z POSITION
ENTRY 7 IS THE END-EFF. X POS. ERROR
ENTRY 8 IS THE END-EFF. Y POS. ERROR
ENTRY 9 IS THE END-EFF. Z POS. ERROR
ENTRY 10 IS END-EFF. X ROT. POS. ERROR
ENTRY 11 IS END-EFF. Y ROT. POS. ERROR
ENTRY 12 IS END-EFF. Z ROT. POS. ERROR

ENTER Y VALUE TO BE PLOTTED

3

FOR WHICH ARM WOULD YOU LIKE TO PLOT VALUES?
INPUT 0 WHEN FINISHED ENTERING ALL PLOTS
TO BE DRAWN FROM THIS PLOT FILE.

0

ENTER DESIRED PLOT TITLE
MAXIMUM OF 40 CHARACTERS
*** LAST CHARACTER MUST BE "\$" ***
TIME VS. JOINT REF. ANGLE AND POS. ERR.\$

ENTER DESIRED HORIZONTAL (X) AXIS LABEL
MAXIMUM OF 40 CHARACTERS
*** LAST CHARACTER MUST BE "\$" ***
TIME\$

ENTER DESIRED VERTICAL (Y) AXIS LABEL
MAXIMUM OF 40 CHARACTERS
*** LAST CHARACTER MUST BE "\$" ***
JOINT 1 REF. ANGLE AND POS. ERROR\$

***** DI-3000 ... HP 7221 DEVICE DRIVER *****

Please enter paper size (1 OR 2)
(1) --- 11 BY 8 1/2 INCHES (DEFAULT)
(2) --- 16 1/2 BY 11 INCHES

1

Please enter pen velocity (1, 2, or 3)
(1) --- 10 CM/SEC
(2) --- 20 CM/SEC
(3) --- 36 CM/SEC (DEFAULT)

2

PLEASE ENTER PAPER TYPE (1 OR 2)
(1) --- SINGLE SHEET - MANUAL FEED
(2) --- CONTINUOUS FEED ROLL (7221S ONLY)

FOR SINGLE SHEET YOU WILL BE PROMPTED TO ENTER A
NEW SHEET OF PAPER AFTER EACH PICTURE.
FOR CONTINUOUS FEED THE PAPER WILL ADVANCE AUTOMATICALLY AFTER EACH PICTURE

1

Ready for graphics. Please turn on plotter and
insert paper for first plot.
Hit RETURN when ready to continue

<CR>

ENTER 1 FOR CONTINUOUS CURVE
ENTER 2 TO PLOT AS POINTS

1

Pause requested. Hit [RETURN] to continue.

<CR>
A-220

ENTER 1 FOR CONTINUOUS CURVE
ENTER 2 TO PLOT AS POINTS

1

Pause requested. Hit [RETURN] to continue.

<CR>

Pause requested. Hit [RETURN] to continue.

<CR>

<Normal termination. Please remove plot.

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REPLAY GRAPHIC SIMULATION MOTION ONLY
2	REPLAY GRAPHIC SIMULATION VERSUS HARDWARE MOTION
3	PARAMETER VERSUS PARAMETER PLOTS
4	TERMINATE POST PROCESSOR EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

3

THIS PROGRAM USES THE DI3000 GRAPHICS SYSTEM
THE FOLLOWING SETUP PROCEDURES MUST HAVE BEEN
PERFORMED:

RUN THE COMMAND FILE FOR DI3000 SETUP:
@SYSWDI:DI3000

FOR HP 7221 PLOTTING RUN COMMAND FILE:
HPSETUP

FOR VT125 PLOTTING RUN COMMAND FILE:
VTSETUP

ENTER 1 TO TERMINATE PLOT SUBROUTINE IF THIS
HAS NOT BEEN DONE

ENTER RETURN TO CONTINUE

<CR>

ENTER NAME OF FILE CONTAINING DATA FOR PLOTS
MAX OF 40 CHARACTERS EXAMPLE - ROBDEVICE:[ROBDIR]PLANSIM.PLT
PLNDET7.PLT

DO YOU WISH AUTOMATIC SCALING?
ENTER Y FOR YES
ENTER N FOR NO

Y

THERE ARE 1 ARMS IN THIS SYSTEM

ARM 1 HAS 2 JOINTS

FOR WHICH ARM WOULD YOU LIKE TO PLOT VALUES?
INPUT 0 WHEN FINISHED ENTERING ALL PLOTS
TO BE DRAWN FROM THIS PLOT FILE.

1

FOR WHICH JOINT OF ARM 1 WOULD YOU LIKE TO PLOT VALUES?
FOR END-EFFECTOR VALUES, ENTER VALUE THAT IS
ONE MORE THAN THE NUMBER OF JOINTS.
IF NOT A JOINT OR END-EFFECTOR VALUE, ENTER ZERO.

1

THERE ARE 31 Y VALUES AVAILABLE FOR PLOTTING.

ENTRY 1 IS THE AMPLIFIER VOLTAGE VALUE
ENTRY 2 IS THE REF. X POSITION VALUE
ENTRY 3 IS THE REF. Y POSITION VALUE
ENTRY 4 IS THE REF. Z POSITION VALUE
ENTRY 5 IS THE USER GIVEN REF. X FORCE
ENTRY 6 IS THE USER GIVEN REF. Y FORCE
ENTRY 7 IS THE USER GIVEN REF. Z FORCE
ENTRY 8 IS REF. FORCE ROT. VECT. X
ENTRY 9 IS REF. FORCE ROT. VECT. Y
ENTRY 10 IS REF. FORCE ROT. VECT. Z
ENTRY 11 IS THE END EFF. X POSITION
ENTRY 12 IS THE END EFF. Y POSITION
ENTRY 13 IS THE END EFF. Z POSITION
ENTRY 14 IS THE END EFF. X FORCE
ENTRY 15 IS THE END EFF. Y FORCE
ENTRY 16 IS THE END EFF. Z FORCE
ENTRY 17 IS THE END EFF. X TORQUE
ENTRY 18 IS THE END EFF. Y TORQUE
ENTRY 19 IS THE END EFF. Z TORQUE
ENTRY 20 IS THE ERROR IN X POSITION
ENTRY 21 IS THE ERROR IN Y POSITION
ENTRY 22 IS THE ERROR IN Z POSITION
ENTRY 23 IS THE ERROR IN POS. X ROT. VALUE
ENTRY 24 IS THE ERROR IN POS. Y ROT. VALUE
ENTRY 25 IS THE ERROR IN POS. Z ROT. VALUE
ENTRY 26 IS THE ERROR IN X FORCE/TORQUE
ENTRY 27 IS THE ERROR IN Y FORCE/TORQUE
ENTRY 28 IS THE ERROR IN Z FORCE/TORQUE
ENTRY 29 IS THE ERROR IN X ROT. FORCE/TORQUE
ENTRY 30 IS THE ERROR IN Y ROT. FORCE/TORQUE
ENTRY 31 IS THE ERROR IN Z ROT. FORCE/TORQUE

ENTER Y VALUE TO BE PLOTTED

1

FOR WHICH ARM WOULD YOU LIKE TO PLOT VALUES?
INPUT 0 WHEN FINISHED ENTERING ALL PLOTS
TO BE DRAWN FROM THIS PLOT FILE.

1

FOR WHICH JOINT OF ARM 1 WOULD YOU LIKE TO PLOT VALUES?
FOR END-EFFECTOR VALUES, ENTER VALUE THAT IS
ONE MORE THAN THE NUMBER OF JOINTS.
IF NOT A JOINT OR END-EFFECTOR VALUE, ENTER ZERO.

2

THERE ARE 31 Y VALUES AVAILABLE FOR PLOTTING.
ENTRY 1 IS THE AMPLIFIER VOLTAGE VALUE
ENTRY 2 IS THE REF. X POSITION VALUE
ENTRY 3 IS THE REF. Y POSITION VALUE
ENTRY 4 IS THE REF. Z POSITION VALUE
ENTRY 5 IS THE USER GIVEN REF. X FORCE
ENTRY 6 IS THE USER GIVEN REF. Y FORCE
ENTRY 7 IS THE USER GIVEN REF. Z FORCE
ENTRY 8 IS REF. FORCE ROT. VECT. X
ENTRY 9 IS REF. FORCE ROT. VECT. Y
ENTRY 10 IS REF. FORCE ROT. VECT. Z
ENTRY 11 IS THE END EFF. X POSITION
ENTRY 12 IS THE END EFF. Y POSITION
ENTRY 13 IS THE END EFF. Z POSITION
ENTRY 14 IS THE END EFF. X FORCE
ENTRY 15 IS THE END EFF. Y FORCE
ENTRY 16 IS THE END EFF. Z FORCE
ENTRY 17 IS THE END EFF. X TORQUE
ENTRY 18 IS THE END EFF. Y TORQUE
ENTRY 19 IS THE END EFF. Z TORQUE
ENTRY 20 IS THE ERROR IN X POSITION
ENTRY 21 IS THE ERROR IN Y POSITION
ENTRY 22 IS THE ERROR IN Z POSITION
ENTRY 23 IS THE ERROR IN POS. X ROT. VALUE
ENTRY 24 IS THE ERROR IN POS. Y ROT. VALUE
ENTRY 25 IS THE ERROR IN POS. Z ROT. VALUE
ENTRY 26 IS THE ERROR IN X FORCE/TORQUE
ENTRY 27 IS THE ERROR IN Y FORCE/TORQUE
ENTRY 28 IS THE ERROR IN Z FORCE/TORQUE
ENTRY 29 IS THE ERROR IN X ROT. FORCE/TORQUE
ENTRY 30 IS THE ERROR IN Y ROT. FORCE/TORQUE
ENTRY 31 IS THE ERROR IN Z ROT. FORCE/TORQUE

ENTER Y VALUE TO BE PLOTTED

1

FOR WHICH ARM WOULD YOU LIKE TO PLOT VALUES?
INPUT 0 WHEN FINISHED ENTERING ALL PLOTS
TO BE DRAWN FROM THIS PLOT FILE.

0

ENTER DESIRED PLOT TITLE
MAXIMUM OF 40 CHARACTERS
*** LAST CHARACTER MUST BE "\$" ***
TIME VS. JOINT VOLTAGES\$

ENTER DESIRED HORIZONTAL (X) AXIS LABEL
MAXIMUM OF 40 CHARACTERS

*** LAST CHARACTER MUST BE "\$" ***

TIME\$

ENTER DESIRED VERTICAL (Y) AXIS LABEL
MAXIMUM OF 40 CHARACTERS

*** LAST CHARACTER MUST BE "\$" ***

JOINT 1 AND JOINT 2 VOLTAGES\$

***** DI-3000 ... HP 7221 DEVICE DRIVER *****

Please enter paper size (1 OR 2)

(1) --- 11 BY 8 1/2 INCHES (DEFAULT)

(2) --- 16 1/2 BY 11 INCHES

1

Please enter pen velocity (1, 2, or 3)

(1) --- 10 CM/SEC

(2) --- 20 CM/SEC

(3) --- 36 CM/SEC (DEFAULT)

2

PLEASE ENTER PAPER TYPE (1 OR 2)

(1) --- SINGLE SHEET - MANUAL FEED

(2) --- CONTINUOUS FEED ROLL (7221S ONLY)

FOR SINGLE SHEET YOU WILL BE PROMPTED TO ENTER A
NEW SHEET OF PAPER AFTER EACH PICTURE.

FOR CONTINUOUS FEED THE PAPER WILL ADVANCE AUTOMATICALLY AFTER EACH PICTURE

1

Ready for graphics. Please turn on plotter and
insert paper for first plot.

Hit RETURN when ready to continue

<CR>

ENTER 1 FOR CONTINUOUS CURVE

ENTER 2 TO PLOT AS POINTS

1

Pause requested. Hit [RETURN] to continue.

<CR>

ENTER 1 FOR CONTINUOUS CURVE

ENTER 2 TO PLOT AS POINTS

1

Pause requested. Hit RETURN| to continue.

<CR>

Pause requested. Hit RETURN| to continue.

<CR>

Normal termination. Please remove plot.

SELECT MODE OF OPERATION DESIRED

MODE	DEFINITION
1	REPLAY GRAPHIC SIMULATION MOTION ONLY
2	REPLAY GRAPHIC SIMULATION VERSUS HARDWARE MOTION
3	PARAMETER VERSUS PARAMETER PLOTS
4	TERMINATE POST PROCESSOR EXECUTION

ENTER INTEGER VALUE FOR MODE DESIRED
(911 FOR THE ROBSIM HELP LIBRARY)

4

EXITING FROM POST PROCESSING FUNCTION
FORTRAN STOP

INPUT (Y) TO RUN SYSTEM DEFINITION FUNCTION AGAIN, (OTHERWISE, RETURN) <CR>
INPUT (Q) IF YOU WISH TO EXIT THE PROGRAM (OTHERWISE, RETURN)Q

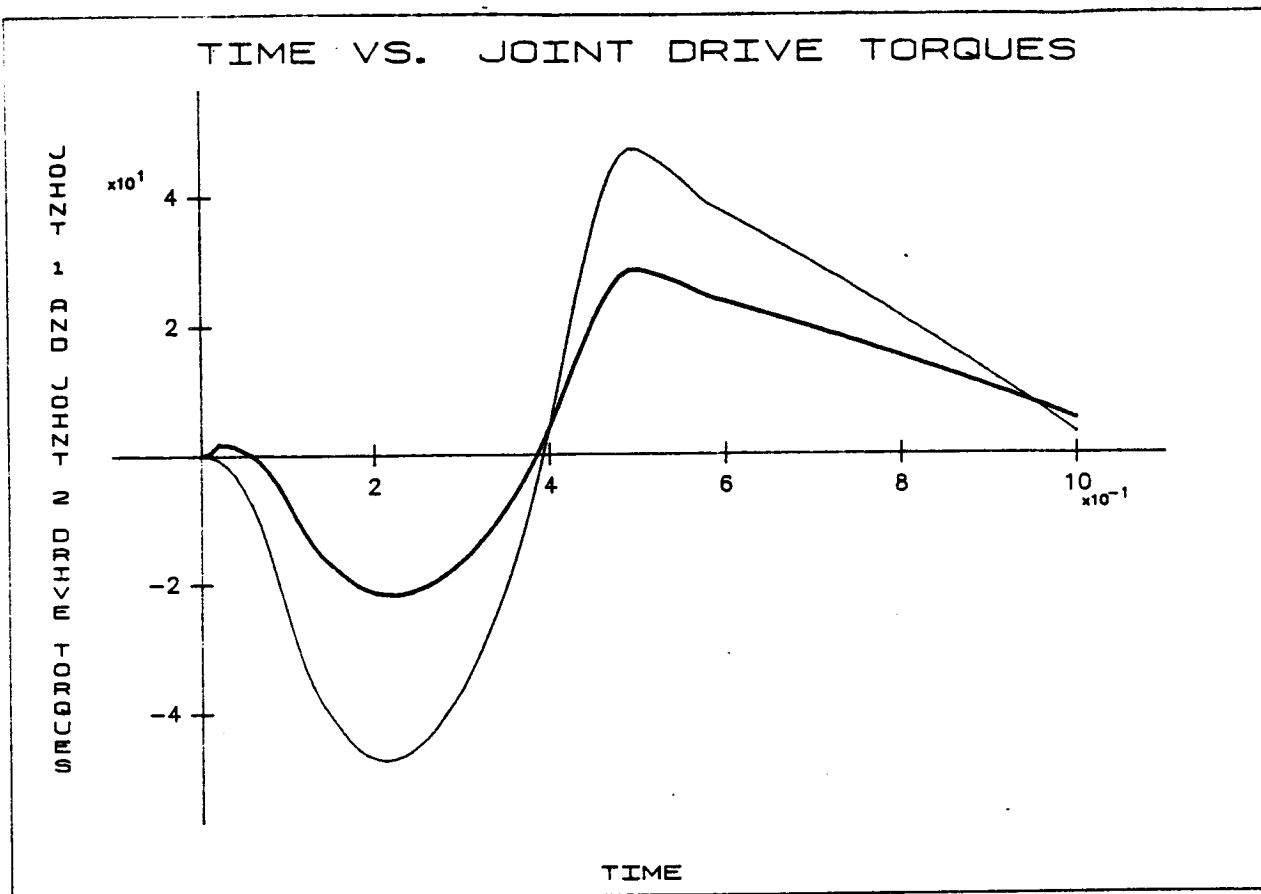


Figure A-36. - Postprocessor sample plot of combination package option.

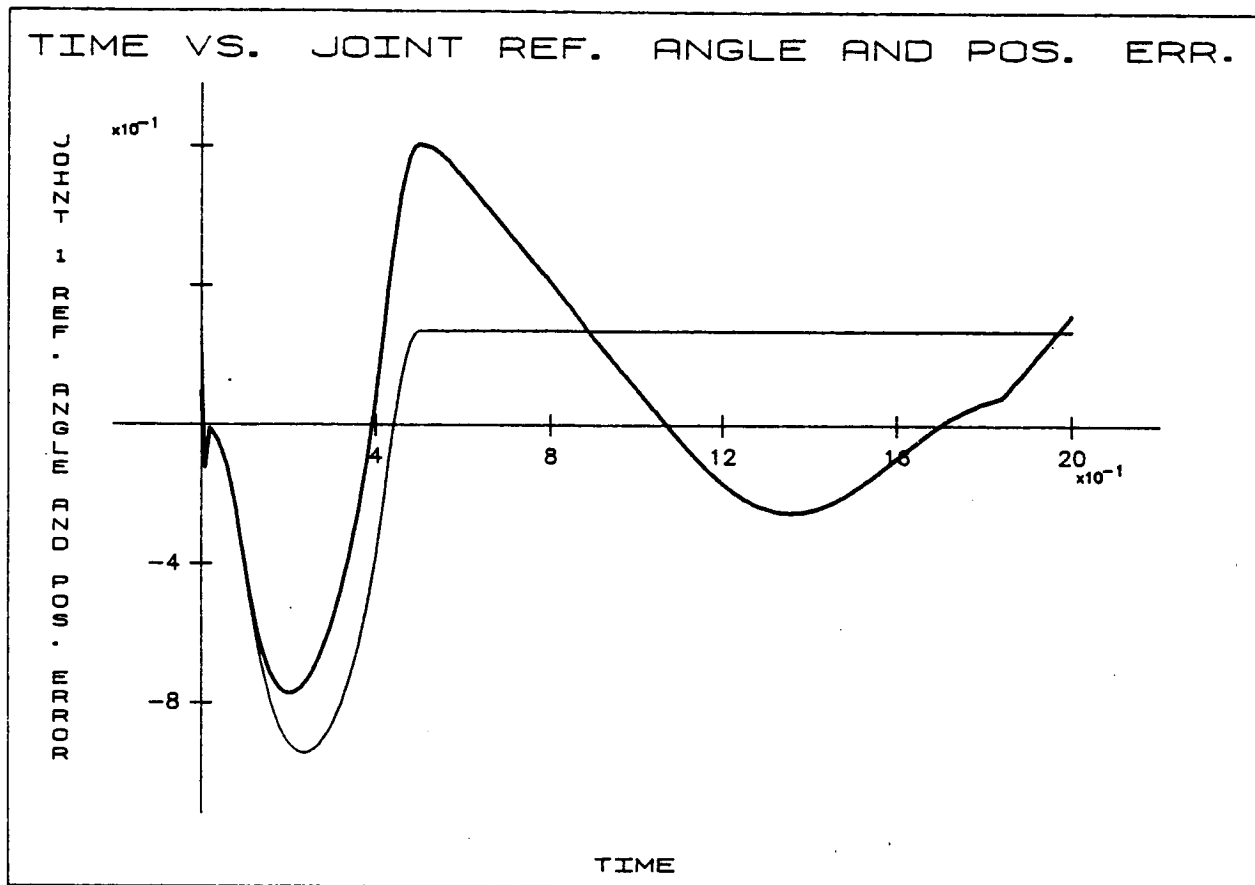


Figure A-37. - Postprocessor sample plot of PID control package option.

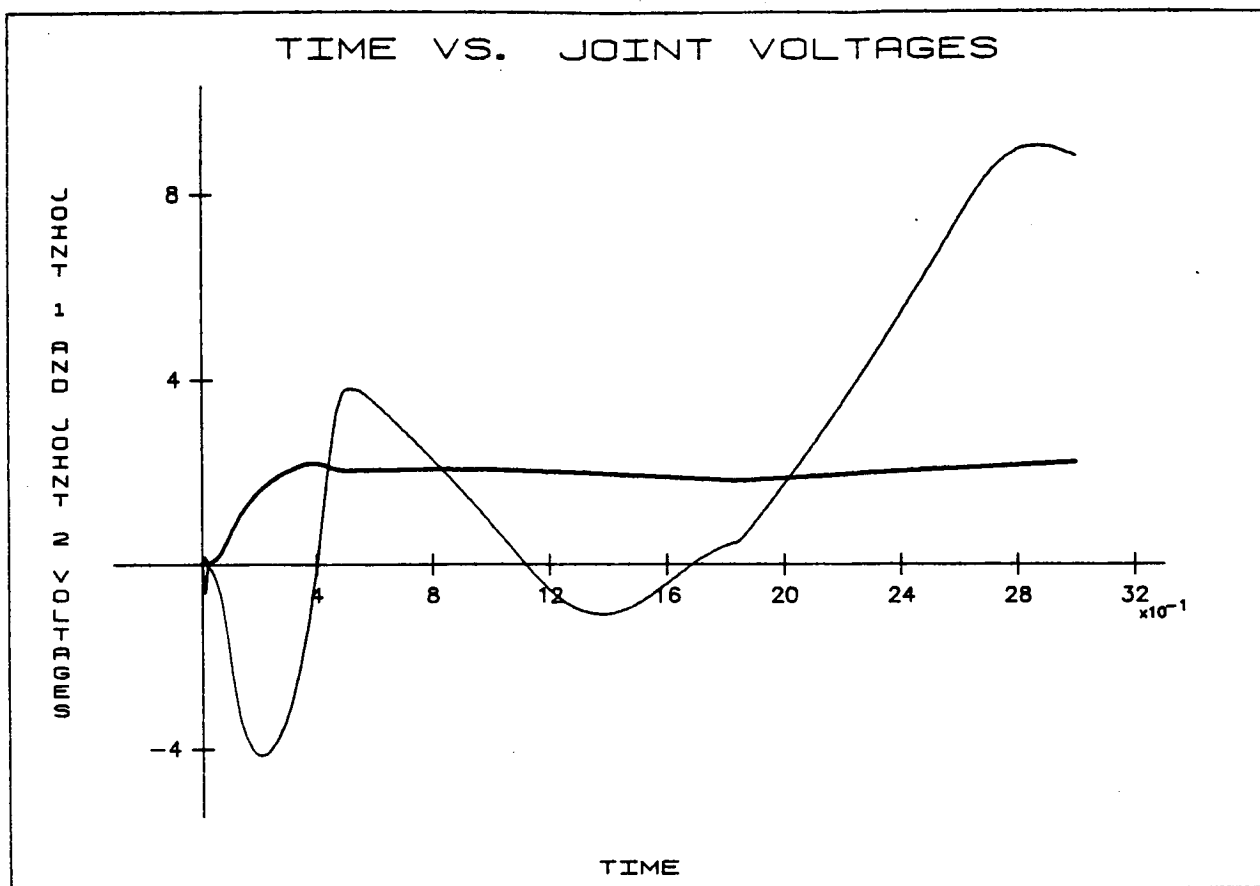


Figure A-38. - Postprocessor sample plot of force/torque package option.

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4. Title and Subtitle Evaluation of Automated Decisionmaking Methodologies and Development of an Integrated Robotic System Simulation				5. Report Date September 1984	
				6. Performing Organization Code	
7. Author(s) D. C. Haley, B. J. Almand, M. M. Thomas, L. D. Krauze, K. D. Gremban, J. C. Sanborn, J. H. Kelly, T. M. Depkovich				8. Performing Organization Report No. MCR-84-549	
				10. Work Unit No.	
9. Performing Organization Name and Address Martin Marietta Aerospace Denver Aerospace P.O. Box 179 Denver, CO 80201				11. Contract or Grant No. NAS1-16759	
				13. Type of Report and Period Covered Contractor Report	
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546				14. Sponsoring Agency Code	
15. Supplementary Notes Langley Technical Monitor: Jack Pennington Report Consists of Three Volumes: Study Results, Appendix A—User's Guide, Appendix B—Programmer's Guide					
16. Abstract This report covers the work performed on tasks 9—20 of contract NAS1-16759. The work done under this contract implemented a generic computer simulation for manipulator systems (ROBSIM) and developed the specific technologies necessary to increase the role of automation in various missions. The specific items developed are: 1) Capability for definition of a manipulator system consisting of multiple arms, load objects, and an environment; 2) Capability for kinematic analysis, requirements analysis, and response simulation of manipulator motion; 3) Postprocessing options such as graphic replay of simulated motion and manipulator parameter plotting; 4) Investigation and simulation of various control methods including manual force/torque and active compliance control; 5) Evaluation and implementation of three obstacle avoidance methods; 6) Video simulation and edge detection; 7) Software simulation validation. The tasks listed above are documented in the study results volume of this report. Appendix A is the user's guide and includes examples of program runs and outputs as well as instructions for program use. Appendix B, the programmer's guide, defines the program structure and includes a VCLR and short explanation for each subroutine.					
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